# AIRLIFT SYSTEM SENSITIVITY TO PERTURBED TIME-PHASED FORCE DEPLOYMENT DATA

THESIS

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AFIT/GOA/ENS/96M-07



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THESIS

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Glenn G. Rousseau

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## Abstract

This research evaluated the effects of perturbations in time-phased force deployment data (TPFDD) on airlift system performance. Four characteristics of two TPFDD files were perturbed according to a $2^{4-1}$ fractional factorial experimental design and then fed into the Airlift Flow Module (AFM) simulation. Specifically, small, constrained perturbations were made to the specified locations, the timeline, the amounts of cargo and passengers, and the proportion of outsize and oversize cargo categories. The effects these perturbations had on AFM output were interpreted using factor analysis. The computed factor scores, when plotted against one another, provided sensitivity plots, graphically depicting the sensitivity of the airlift performance response to the perturbations. Counter to recent airlift analysis discussions which promote completely unconstrained random TPFDD generation, this research indicated that small, constrained variations could cause potentially significant and unpredictable changes in airlift performance. Of potential interest to the simulation community, another by-product of this research was the potential to use factor analysis as a verification and validation tool for large, complex simulation models.

# AIRLIFT SYSTEM SENSITIVITY TO PERTURBED TIME-PHASED FORCE DEPLOYMENT DATA

## I. Introduction

### General Issue

Air Mobility Command (AMC) makes resource and policy decisions for an airlift system that is driven by Time-Phased Force Deployment Data (TPFDD) specifying airlift movement requirements. A properly sequenced TPFDD is the result of a long process that takes 12 to 18 months, and lists, in much detail, how US forces will be deployed (Lund and others, 1993:24). TPFDDs are important to many planning and decision processes within the Department of Defense.

AMC's decision process typically requires insight from some of the analytic tools used by AMC's Studies and Analysis Flight (AMCSAF). In particular, the output from their Mobility Analysis Support System's (MASS) Airlift Flow Module (AFM), a large-scale simulation model, is typically used to predict airlift system performance. AFM requires a TPFDD as input because, like the airlift system itself, AFM is highly dependent upon specific transportation requirements. Currently, for lack of a better method, analysis of airlift system performance in any given conflict is based on the prioritized cargo and passenger movement requirements in only one TPFDD.

In considering the quality of analysis of airlift system performance based on one TPFDD, several questions arise: Can AMC make the best decisions based on a single TPFDD? How sensitive is the performance of the airlift system to changes or errors in the TPFDD? If we vary the TPFDD, can we gain a better understanding of what is the expected performance? Can an approach be devised to reduce the uncertainty in our expectations of how the airlift system will behave by varying or perturbing a TPFDD? Is there a way to assess or evaluate airlift system performance across multiple scenarios?

A recent example, though not an AMC decision, highlights some of these questions. A significant input to the decision to purchase more C-17 aircraft was a large and detailed simulation study, the Strategic Airlift Force Mix Analysis (SAFMA), which was based on a single, much debated TPFDD (AMMP, 1996: 1-26). Though the validity of the results of that study are not in question, one has to ask if the resulting decision will provide the best airlift fleet for all possible future airlift taskings? Is it possible to place a statistical envelope around the study results, effectively bounding airlift system performance across several similar scenarios? Would the decision change given a different scenario? Would it prove to be robust across multiple scenarios?

In a briefing given to the Defense Acquisition Board in November of 1995, the major selling point for the C-17 was its relative insensitivity to a 15 percent loss in available MOG, or parking space (Merrill, 1995). If the TPFDD were slightly different, would the results from this MOG resource reduction prove to be similar? Is it possible to perturb the given TPFDD, without changing network resources, to obtain similar results or to validate the assumed insensitivity of the results to different scenarios?

Translating the previous example to military force structure planning in general, it appears that the C-17 purchase decision was no different than that of buying the next fighter or tank, or deciding the size and composition of the 2005 light infantry battalion. Current military force structure analysis requires the assumption of a single scenario and strategy. This assumption comes in the form of time-phased force deployment data (TPFDD), which contains the desired flow of cargo and personnel corresponding to the war plan for that scenario. A typical TPFDD is large and detailed, but it has many weaknesses when used as a transportation requirement database for analysis (Yost, 1995: 30-33). In the case of the SAFMA study, the only TPFDD used was the result of the Mobility Requirements Study Bottom-Up Review Update (MRS-BURU) which was completed in December 1994 (AMMP, 1995: 1-25).

Ten years ago, it was sufficient to plan and buy for the one big threat, the Union of Soviet Socialist Republics (USSR). At the time, the assumption was: if we could defeat the USSR, any other war would be easier (Hagin: 1995). Today's military planning cannot rely on the same assumption because it is no longer valid. With less money, a more complex global situation, and less of our military stationed outside the Continental United States (CONUS), threat-driven analyses are harder to accomplish and harder still to use as a basis for justifying substantial allocations of resources that take a decade to acquire and then will be in service for 25 years or more (Gebman et al, 1994: 35).

Ensuring the robustness of decisions will require analysis across a spectrum of possible scenarios or TPFDDs (Yost, 1995: 33). Since TPFDDs define a current "best" strategy for a given conflict, they contain pertinent scenario-specific data. However, due

to the inherent uncertainty in a given TPFDD, airlift analysis should also consider variations of the given TPFDD.

In this light, this research effort considered randomly perturbing two existing TPFDDs to provide different TPFDD variations for analysis. The two unclassified TPFDDs used in this study were provided by AMCSAF in the format required for AFM input. This format obscures some of the detail normally provided by an actual TPFDD and contains only the airlift portion of a complete TPFDD. The AFM input file containing the TPFDD is known as a file 63 (see Appendix A). The argument up to this point for a TPFDD can be directly applied to a file 63 without loss of generality. From this point forward, however, TPFDD will be used to represent the original requirements listing in its original format. File 63 will be used to represent the pre-processed airlift portion of the TPFDD that is formatted for AFM input.

## Problem Statement

Current analysis of the airlift system is restricted by a reliance on the details of a given TPFDD. AMCSAF desires a methodology to understand and evaluate airlift system performance over a variety of scenarios, without such a strong reliance on the exact details of a given TPFDD.

## Research Objectives

The focus of this research effort will be on perturbing the two provided files 63 to examine the effects the perturbations have on selected measures of effectiveness (MOE's).

The desired approach follows these general steps, which are discussed further in Chapter III:

1) Identify AFM output variables reflecting desired MOE's
2) Analyze sensitivities to AFM random seed using factor analysis
3) Define perturbation schemes
4) Analyze sensitivities to perturbations using factor analysis

This thesis documents, in detail, the process of perturbing a given file63. In particular, it describes the means by which these perturbations are constrained to represent operationally realistic and transportationally feasible TPFDDs. This thesis also documents the impact of this perturbation process on the variability of the AFM output. The application of perturbed TPFDD's to a robust analytical methodology is also demonstrated. Finally, a discussion of results and conclusions, including the benefits of this process to future AMC airlift policies and force planning, is presented.

## Thesis Organization

The next chapter identifies related research efforts and provides background information on major topics pertinent to this research: the AFM simulation, the TPFDD creation process, TPFDD parameters and uncertainty, airlift system performance, and factor analysis. Chapter III will discuss the details of the outlined process and the methodology used to apply that process to analysis of airlift system performance. Chapter IV will discuss the input and output data. Finally, Chapter V will present the resulting recommendations and conclusions.

# II. Background Information

## Introduction

This chapter discusses the literature review and other background information pertinent to: the AFM simulation, the TPFDD creation process, TPFDD parameters and uncertainty, airlift system performance, and factor analysis techniques.

## Literature Review

This thesis topic originated from conversations at AMCSAF on theoretical possibilities of unconstrained random TPFDD generation for airlift system performance analysis (Revetta, 1995). This thesis topic evolved as an exploratory look at the possibilities of using randomly generated TPFDDs for airlift analysis.

Though perturbations to the TPFDD seem to interest many in the strategic transportation community, little has been documented as to how these perturbations might affect strategic lift capability. Conversations with OSD PA&E indicated they would soon be sponsoring research into the effects perturbed TPFDDs have on the performance of all transportation modes (Schaefer, 1995).

The earliest reference found, supporting the problem with using only one scenario for airlift analysis, was a dissertation by Colgan, who conducted a cost effectiveness study. The relationship of cost effectiveness to performance seems fairly direct, and the arguments and observations Colgan used regarding the "right mission" for analysis apply equally well to analysis of airlift performance. He raised the question of the validity of a

fixed TPFDD, and proposed using a combination of TPFDDs in evaluating system performance (Colgan, 1967: 85).

A study by Ulusoy and Uzsoy indicated the lack of research literature related to robust strategic airlift performance across multiple scenarios (Ulusoy and Uzsoy, 1992: 275). They presented a linear programming formulation of a strategic airlift problem that includes generating a set of scenarios over a set of possible demand patterns. This is the only literature found that addressed the problem of airlift system performance analysis using a generated set of scenarios. Their model, however, solves an aircraft location problem that is dependent upon total throughput as the basis for the result (Ulusoy and Uzsoy, 1992: 266-276). Besides simplistic airlift system constraints, the difficulty of extrapolating their model to include time-phased data and detailed dimensions of airlift performance did not seem appropriate for this research.

A practical and sometimes humorous assessment of the current state of airlift system modeling and analysis, as expressed in a recent PHALANX article, highlighted the fallacies involved with using only one TPFDD for analysis. The article went further to propose using multiple scenarios (TPFDDs) in pursuit of more robust analysis (Yost, 1995: 30-33).

Robinson was another proponent of using multiple scenarios for airlift system analysis. His contextual analysis of air transportation systems proposed and supported analysis of varying scenarios, but he completely disregarded the TPFDD as the basis for his scenarios (Robinson, 1993).

Hanson successfully applied factor analysis during his analysis of the output from the MINOTAUR mobility simulation model. His research did use a TPFDD to define the scenario, but he did not attempt to perturb the TPFDD and his analytical objectives were quite different than the objectives of this thesis (Hanson, 1990).

## The AFM Simulation

The Mobility Analysis Support System (MASS), maintained by AMCSAF, is a collection of computer models and utilities, written mostly in FORTRAN, that provide for detailed analysis of airlift system performance. The centerpiece of MASS is the Airlift Flow Module (AFM), a requirements driven simulation that plans missions deterministically and executes stochastically (AFM Documentation, 1996). The *requirements* are contained in the file 63, which is derived from the TPFDD. These requirements "drive" the simulation processes because AFM *deterministically* reads the file 63 sequentially from the top, line by line, until it identifies the first available and compatible cargo for the next available aircraft. Once AFM finishes planning the mission, the aircraft's flight and ground times used during *execution* of the mission are drawn from random distributions. AFM release 4 was used for this research effort. The following summary of AFM input, planning, execution, and output is from an AMCSAF point paper provided to Congressional Budget Office analysts in October 1993 (Merrill, 1993):

Inputs. Inputs to the AFM include:

- a TPFDD containing airlift movement requirements
- an airlift network of onloads, offloads, en-route stops, recovery bases, and home stations connected by user-defined routes
- an airlift fleet mix of different aircraft types identified by individual tail numbers

- individual aircrews who must be available to allow missions to be flown
- logistics factors which account for refueling, maintenance, and material handling of cargo
- concepts of operation that include strategic intertheater airlift, aerial refueling, intratheater shuttle operations, direct delivery operations, and recovery/stage operations

Planning. Mission planning in the AFM accomplishes:

- Prioritization of requirements by available-to-load dates and required delivery dates
- Prioritized route selection and reservation for flight planning
- Marrying a specific aircraft tail number to the next eligible requirement
- Crew planning to ensure that only the crews eligible to fly do fly

Execution. Mission execution in the AFM simulates:

- Typical sortie events, including: taxi-out, takeoff, departure, en-route cruise, initial approach, final approach, landing, taxi-in, and ground activities for every sortie of every mission
- Ground activity resource allocation and planned delays for: ramp space, offloading cargo, refueling, maintenance, onloading cargo, and crew changing
- Optionally, detailed loading of each piece of cargo for compatibility with doors and remaining space on each aircraft
- Crew activities and monitoring events, including: crew rest, crew monthly and quarterly flying hour limits, crew availability, and searches for unavailable crews

Output. Output from the AFM includes:

- Aircraft-related statistics, such as: utilization rate, payload, ground service time, flight time, and system delays
- Aircrew-related statistics, such as: crew duty day, number of crews, hours flown by each crew, and crew availability
- Cargo-related statistics: total tons delivered, tons per day throughput, unit and force closure, actual million ton miles per day flown, and cargo remaining in backlog
- Airlift network statistics: typical cycle times, flying times, network airfield use, MOG constraints, and system bottlenecks

Configuration and Setup. To help minimize the setup time and to ensure valid configurations for typical AFM inputs, AMCSAF provided all input files for this research

effort. The two complete data sets provided were extracted from data sets used in previous AMCSAF studies. One setup represented a large scale conflict in the Middle East, similar to DESERT SHIELD/DESERT STORM. The other setup represented a much smaller scale conflict in the Caribbean. These two setups will, for simplicity, be called the large and small scenarios, respectively. Figure 2-1 illustrates the differences between the two scenarios in terms of the total airlift requirement.

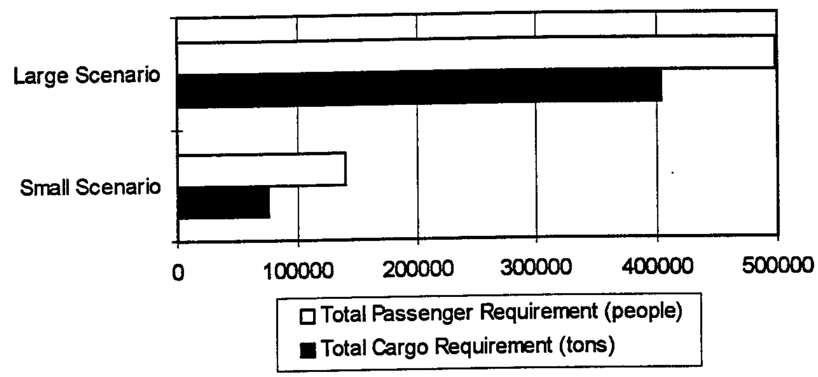


Figure 2-1. Large and Small Scenario Total TPFDD Requirements

Table 2-1 shows the difference in the number of available aircraft in each scenario.

Table 2-1. Available Aircraft (by type) for Research Scenarios

| | C-5A | C-141B | C-17 | KC-10 | B-747[1] | B-747P[2] | DC-8 |
|---|---|---|---|---|---|---|---|
| Large Scenario | 95 | 75 | 51 | 37 | 60 | 90 | 40 |
| Small Scenario | 28 | 56 | 15 | 28 | 0 | 11 | 0 |

Note 1. B-747 is used to represent a Boeing 747 configured for cargo only.
Note 2. B-747P is used to represent a Boeing 747 configured for pax only.

Airlift aircraft types vary in size and capability, and therefore, cargo must somehow be categorized to identify its compatibility with each aircraft type. For airlift, typical categories are: outsize cargo, oversize cargo, bulk cargo, and passengers (or pax).

Outsize cargo is largest category and requires use of C-5 or C-17 aircraft. Oversize cargo exceeds the usable dimensions of a standard 463L pallet, but is within the dimension requirements of the C-141B and C-130 cargo doors and cargo compartments. Oversize cargo requires a C-130 or larger aircraft, or a freight-configured wide-body civil transport. Bulk cargo includes cargo that is within the usable dimensions of a 463L pallet, and can be carried on most aircraft (AMMP, 1996: 1-10).

Assumptions about how to use an aircraft that can carry both passengers and cargo will make a large difference in the performance of the airlift system. For this research, from the modeling standpoint, assumptions about cargo and passenger compatibility are coded in the AFM input file 32. Table 2-2 presents a these compatibility codes.

Table 2-2. AFM Cargo and Passenger Compatibility with Modeled Aircraft Types

| | Cargo and Pax Compatibility Codes[3] | | | |
|---|---|---|---|---|
| | Outsize | Oversize | Bulk | Pax |
| C-5A | 2 | 2 | 1 | 1 |
| C-141B | 0 | 2 | 2 | 1 |
| C-17 | 2 | 2 | 2 | 1 |
| KC-10 | 0 | 1 | 2 | 0 |
| B-747[1] | 0 | 0 | 2 | 0 |
| B-747P[2] | 0 | 0 | 0 | 2 |
| DC-8 | 0 | 0 | 2 | 0 |

Note 1. B-747 is used to represent a Boeing 747 configured for cargo only.
Note 2. B-747P is used to represent a Boeing 747 configured for pax only.
Note 3. Compatibility Codes (See AFM File 32 documentation for more):
2 = cargo category is preferred by this aircraft type
1 = cargo category is compatible with this aircraft type
0 = cargo category is not compatible with this aircraft type.

Of all the AFM input files, only the files 63 (the input files containing airlift requirements) for both the large and small scenarios were changed during the course of the research. AMCSAF suggested switch settings that limited the number of output files

and minimized runtimes. Minimal runtimes were beneficial to completing this research in the time allotted. Another suggestion that was implemented was to specify an early termination date for the simulation. It typically takes 30 to 45 days for the first sealift deliveries to arrive to a theater of war. Therefore, the first 30 or 45 days of the conflict are known as the airlift surge period, where airlift is responsible for delivering the necessary equipment, personnel, and firepower to halt the enemy advance (AMMP, 1995: 1-22, 23). For this research, day 30 was considered the end of the surge period, and both the large and small scenarios were terminated at that point to gather the output statistics.

Time-Phased Force Deployment Data (TPFDD)

There are at least two different kinds of TPFDDs, basically classified by purpose. Those used in the deliberate planning process for operational plan (OPLAN) development are very specific, receive a lot of attention, and are frequently updated because they focus against a specific threat for a limited time span. OPLAN TPFDDs become an annex to the actual war plan and contain the most accurate information possible within each requirement (Hanson, 1990: 5). Those used for non-OPLAN purposes, like training, exercises, and long-range resource planning may not be as specific within each requirement, usually containing notional units and equipment that represent our expected force composition for some future period. In future analysis studies, AMCSAF will likely use both kinds of TPFDDs (Steppe, 1995).

A simplified general discussion of the TPFDD creation process starts with the Joint Staff tasking the combatant command CINCs to develop an OPLAN, then:

> Upon tasking, the CINCs develop the concept of operations, which is passed along to the theater service components along with the apportioned

> combat forces and transportation resources. The theater components specify the necessary supporting forces and supplies, translating the whole into a time-phased list of cargo requirements, or time-phased force deployment data (TPFDD). (Schank et al, 1991: 13-14)

Computerized combat simulations are typically used to assess the OPLAN's strategy and risk at this point. If the strategy and risk are satisfactory, then the associated TPFDD is checked for transportation feasibility with at least one computerized mobility model (Schank et al, 1991: 14). Transportation feasibility indicates that current transportation assets can deliver everything listed in the TPFDD in time to effect a successful OPLAN. If not transportationally feasible, the TPFDD goes back to the CINCs, and the process becomes iterative until some certification of transportation feasibility is achieved. Refining conferences are periodically held to balance more detailed transportation feasibility with acceptable risk on the battlefield. From start to finish, it typically takes 12 to 18 months to create a transportationally feasible TPFDD (Lund et al, 1993:24).

Before AFM can use the information contained in a TPFDD, pre-processing utilities are used to convert the TPFDD to the required input file, file 63, format (see Appendix A). The file 63 format contains only 14 fields, which is a great reduction from the 97 fields in the TPFDD (JOPES Manual, 1993: 48-55). Though not all fields are used in either format, it is obvious that AFM does not consider many of the specific TPFDD details.

The individual backgrounds and personalities of the various people involved in the creation of a given TPFDD have an impact on the details of that TPFDD. Since different generals will place different priorities on the 100,000 or more requirement lines that can

comprise a large TPFDD, it is not unreasonable to expect that there could be as many TPFDDs for a given conflict as there are generals (Schank et al, 1991:25). When it comes time to execute a war plan, it is also reasonable to think that the war will not go as planned. As was seen in Desert Storm, the TPFDD changed so frequently that the what, when and where aspects of the TPFDD were completely different from one day to the next (USGAO, 1993: 24-25). These observations introduce the possibility of some degree of uncertainty within any TPFDD. Uncertainty in the TPFDD, however, does not imply the TPFDD is worthless. On the contrary, TPFDDs contain the best information available for their intended purpose, and that is to support the Joint Strategic Planning System in developing feasible operating plans (Schank et al, 1991:13).

### Airlift System Performance

There are many measures of airlift system performance used depending upon the question asked and the data available. It is important to note that fighting unit combat effectiveness is the ultimate measure of airlift system performance, but there is no direct translation between individual pieces of cargo delivered and combat effectiveness (Schaefer, 1995). Combat unit closure statistics are the best statistics for estimating combat effectiveness, but are not easily computed. Since most outsize cargo is combat firepower, a gross measure for estimating combat effectiveness is total outsize tons delivered.

Throughput measures, aggregate measures of total tons or passengers delivered, seem to be very common to all recent airlift studies. A common throughput measure of effectiveness is the million-ton-mile per day (MTM/D) statistic, though its actual

usefulness has been much debated (Robinson, 1993:10-14; also Yost, 1995: 33). Charts depicting throughput, in total tons or numbers of passengers delivered, over time have been interpreted as being preferred by Air Force leadership (Robinson, 1993: 12). The Army troops on the ground facing the enemy, however, have another measure of airlift system performance: did they get the right cargo at the right place, ontime?

Firepower delivered a day late is of no use if the war is already over. The timeliness of deliveries is as critical to combat effectiveness as firepower, so several measures of timeliness performance were included in the data analyzed during this research.

From AMC's perspective, the performance of the individual aircraft types is critical information to managing and improving the airlift system. Aircraft utilization rates, average payloads, and cycle times are common aircraft performance measures of efficiency and productivity. Aircraft utilization rates are typically broken down by aircraft type, and reflect the average number of hours each aircraft of that type flew in an average day. Unless many underlying assumptions are held constant, however, utilization rates and average payload values can be misinterpreted and may not be reliable indicators of performance (Kowalsky, 1977: 1). This observation formed the basis for incorporating AFM subroutines to compute cycle statistics. One aircraft cycle consists of the events that occur between the time the aircraft leaves the blocks at one station until he returns to that station and is ready to leave the blocks again (Kowalsky, 1977: 4-1). Furthermore, each cycle can be broken down into the flying cycle time and the ground cycle time. The flying

cycle time is the cumulative number of hours during the cycle in which the aircraft was flying. The ground cycle time is the remaining time.

Airlift system performance is highly dependent upon crew performance, which is another area that is of concern to AMC leadership. Flying hour limits, crew rest, crew duty days, morale, fatigue, and other crew limitation factors can have a serious impact on airlift system capabilities. Flying hour limits are typically in the form of maximum hours flown in 30, 60, and/or 90 days. Crew rest is the number of hours, including meals, that each crew is entitled to between crew duty periods. Crew duty days limit the number of hours a crew can continuously perform flying-related duties, and can vary based on crew composition or available aircraft equipment, such as the autopilot. Unfortunately, each of these crew limitation factors has some sort of waiver status that can be exercised by the various levels of command. Varying assumptions about these waivers in any airlift system performance study can have a serious impact on the analyst's results and conclusions (Shirley, 1995).

There are many models that estimate the performance of the strategic airlift system. Most of the current strategic mobility models (e.g. ADANS, JFAST, CONOP, THRUPUT, and MIDAS) simulate the airlift system in one way or another, yet few have the flexibility and detail provided for by AFM. AFM has the primary advantage that it simulates the airlift system to the level of the individual aircraft and the individual pieces/pallets of cargo. This detail, however, comes at the cost of long setup times and long run times.

## Factor Analysis

In analyzing the effects of TPFDD perturbations on the selected MASS output parameters, factor analysis was used to analyze the resulting variance of the output parameters. Factor loadings matrices provided pertinent information on the relationships between the variables as they responded to the TPFDD perturbations. In addition, visual pictures of airlift system sensitivity to the TPFDD perturbations were found by plotting the first two factors against each other. These "sensitivity plots" proved to be useful tools for sensitivity analysis.

The origin of factor analysis is usually credited to Spearman, who first used the term "factor analysis" in the context of psychological testing for "general intelligence" in the early 1900's (Basilevsky, 1994: x). After correcting Spearman's model, Burt furthered the psychological applications of the technique but only served to discredit it through fraudulent publications concerning twins (Basilevsky, 1994: x-xi). Statisticians continue to engender debate concerning the validity and appropriateness of factor analysis techniques (Basilevsky, 1994: ix). However, since approximately 1970, there has been an increasing amount of literature on scientific and statistical applications of factor analysis, because there

> "... are tasks to which factor analytic techniques are well suited. Besides being able to reduce large sets of data to more manageable proportions, factor analysis has also evolved into a useful data-analytic tool and has become an invaluable aid to other statistical models such as cluster and discriminant analysis, least squares regression, time/frequency domain stochastic processes, discrete random variables, graphical data displays, and so forth although this is not always recognized in the literature (Basilevsky, 1994: ix)."

The source of debate surrounding factor analysis is attributable to a perceived subjectiveness and arbitrariness in selecting and interpreting a correlation matrix between the factor scores and the original variables. This correlation matrix, called a factor loadings matrix, is one of an infinite number of possible orientations or rotations of the data. Standardized rotation schemes have been proven to optimize different aspects of the factor loadings matrix and provide a mathematical basis to defend selection of one factor loadings matrix out of the theoretical infinite possibilities (Basilevsky, 1994: ix, xi).

Factor analysis is basically a data reduction technique that uncovers common dimensions or factors that link together a set of observed variables through analysis of the variables' common variance. The formal factor analysis model describes each original observable variable in terms of a linear function of unobservable common factors and a single latent unique factor, as shown by equation (1) (Dillon and Goldstein, 1984: 55-61).

$$\mathbf{X} = \Lambda\mathbf{f} + \mathbf{e} \tag{1}$$

where

$\mathbf{X} \equiv$ p-dimensional vector of observed responses
$\mathbf{f} \equiv$ q-dimensional vector of unobservable common factors ($q \ll p$)
$\Lambda \equiv p \times q$ matrix of weights or factor loadings
$\mathbf{e} \equiv$ p-dimensional vector of unobservable unique factors

Assuming that the common factors and the unique factors are uncorrelated with themselves and each other, the covariance matrix of the response vector **X**, denoted by $\Sigma_{xx}$, can be expressed as shown in equation (2) (Dillon and Goldstein, 1984:61-2).

$$\Sigma_{xx} = \Lambda\Lambda^T + \Psi \quad (2)$$

where

$\Sigma_{xx} \equiv$ p × p variance-covariance matrix

$\Lambda \equiv$ p × q matrix of weights or factor loadings

$\Lambda\Lambda^T \equiv$ common part of variance-covariance matrix

$\Psi \equiv$ p × p diagonal matrix containing p unique variances

Once a solution to equation (2) is found, the loadings for a given factor reflect the nature of that factor and is subject to interpretation by the analyst. This interpretation can usually be enhanced by rotating the factor loadings matrix. The rotated matrix of factor loadings represents an alternative interpretation of the data and allows the analyst a degree of flexibility (Dillon and Goldstein, 1984: 88). As mentioned previously, the number of such rotational transformations, orthogonal or oblique, is infinite, leading to criticism that any solution chosen is, mathematically speaking, arbitrary (Basilevsky, 1994: xi). Selection of certain criterion functions can define unique rotations and confront this criticism with more generally accepted statistical practice (Basilevsky, 1994: xii).

A commonly used rotation criteria for the varimax rotation, results in a unique rotation and allows for enhancing the interpretability of the loadings matrix structure. The varimax rotation seeks to maximize the variation of the squared factor loadings within each factor, thereby forcing the loading coefficients to either really high or low values (Dillon and Goldstein, 1984: 91). With not many of the loadings falling into the middle "grey area" it is usually easier to find an interpretation from the loadings matrix structure.

# III. Methodology

## Introduction

This chapter highlights the three steps used to evaluate the sensitivity of airlift system performance to perturbing the TPFDD:

1) Identify AFM output variables reflecting desired MOE's
2) Analyze sensitivities to AFM random seed using factor analysis
3) Define perturbation schemes
4) Analyze sensitivities to perturbations using factor analysis

These four steps form the basis for a general methodology that uses perturbed TPFDDs in airlift system analysis.

## Identify AFM Output Variables Reflecting Desired MOE's

In general, the nature of the problem will determine the measures of effectiveness (MOE's) most useful to the analyst. For this research, in the interest of furthering the concept of perturbing the TPFDD to gain more useful insights into the strategic mobility problem, many experts involved with strategic mobility analysis were solicited to identify which variables measuring airlift system performance should be extracted from the AFM. Each expert had a slightly different view of which MOE's were most important. In the end, due to the varied nature of the responses, it seemed that the more general variables from a few key performance areas, would please most everybody. Four major areas of airlift system performance were considered: timeliness, throughput, aircraft, and aircrew. Future research can build on the various areas of airlift performance, examining more of the specific details.

The AFM allows for user selection of numerous output reports and variables. The following AFM output variables were the desired airlift system performance measures of effectiveness for this study:

<u>Aircraft Performance Measures for Each Aircraft Type</u>
- use rate
- flying time per cycle (or f-cycle time)
- ground time per cycle (or g-cycle time)
- average payload
- average million-ton-miles per aircraft per day delivered

<u>Throughput Measures</u>
- outsize tons delivered
- total cargo tons delivered
- total passengers delivered
- average million-ton-miles per day delivered (MTMPD)

<u>Timeliness Measures</u>
- percent of shipments delivered ontime
- percent of shipments delivered late
- percent of shipments still open
- average number of days late

These logical airlift performance categories are important to notice because the data collected for this research clustered into these groupings during the AFM random seed evaluation phase. Crew performance measures were considered, but then discarded based on suggestions by AMCSAF, due to the longer run times and the complexities of understanding the different ways AFM handles crews (Shirley, 1995). For each run, the AFM simulation was stopped at day 30, the end of the surge period in simulation time, to collect the selected performance measures.

It is obvious to see, from the previous list, that the number of variables measuring airlift system performance will increase with more aircraft types in the scenario. For each run of the large scenario, which contains 7 aircraft types, 43 performance variables were

recorded. For each run of the small scenario, which contains 5 aircraft types, 33 performance variables were recorded.

Analyze Sensitivities to AFM Random Seed Using Factor Analysis

One of the observed weaknesses of the AFM is the lack of documented performance characteristics. In particular, the effects of its own internal random seed on the internal coded processes and the output were unknown (Hagin, 1995). The AFM has 100 well-tested pseudo-random streams from which all stochastic processes get their random values, as required. One stream needs to be initialized as the reference stream for AFM when the simulation is started. All internal AFM processes that require a random value make a call to any one of the 100 pseudo-random streams, depending on the displacement that process adds to the reference stream value. Therefore, changing the reference stream will affect all of AFM's internal stochastic processes. There was no documentation as to the expected variance in any output variable due to running AFM with different initial stream values (Hagin, 1995). Before applying random perturbations to input data, understanding the sensitivities of the model to its internal random seed was essential. The variance of all the output variables from 50 runs was computed individually to quantify the sensitivity of each variable to the random seed (see Appendices B and C).

When evaluating the perturbations, the variance from the random seed runs served as a useful reference measure for internal random noise, a characteristic of any stochastic model. According to Law and Kelton:

> "Each run of a stochastic simulation produces only estimates of a model's true characteristics for a particular set of input parameters. Thus several independent runs of the model will probably be required for each set of input parameters to be studied (Law and Kelton, 1991: 115)."

Since each perturbation of the TPFDD was a new "set of input parameters to be studied," being able to distinguish between variance caused by the model, or characteristics of the model, and variance caused by the TPFDD perturbations was critical to understanding the effects of those perturbations.

For each of the two scenarios provided, the number of runs must be at least as large as the number of recorded variables to ensure enough degrees of freedom to estimate the necessary values for factor analysis (Bauer, 1995). Considering this fact, 50 runs with different initial random streams were made for both the large and the small scenarios.

Data from the large and small scenarios were analyzed separately in an attempt to identify what caused the observed changes in the output. Some variables were eliminated by observation, before using factor analysis. Some of the cycle time variables were eliminated by observation because they didn't output consistently from all 50 runs. For some runs, AFM did not obtain enough cycles for each aircraft type to be able to calculate a value. Other variables were consistently output as zero values because they referred to something that could not happen in the model. For instance, B-747 passenger aircraft could not carry cargo in the simulation, so average payload and MTM/D for this aircraft type were always zero. Other variables were eliminated, iteratively, by comparing their performance against known uniform random noise variables during factor analysis. A reliable set of performance variables was identified by computing the eigenvalues of the correlation matrix and observing that all eigenvalues were greater than zero (Bauer, 1995). Once a reliable set of performance variables was determined, the dimensionality of the performance measures were further reduced by solving for the underlying common

factors with factor analysis. The varimax rotation was used, without exception, to enhance the interpretability of the factor loadings matrix.

Since only the random seed changed from run to run, the simulations internal stochastic processes should be the source of variation in all output variables. In comparison, the main assumption of factor analysis is that there is an unknown set of factors causing all variables in your data set to change. Therefore, the unknown factors, computed from output resulting from multiple runs where the only difference between runs is the change in the random seed, should reflect the internal stochastic processes because they are the only physical explanation for the observed changes in the data set. If the factor loading matrix allows for interpretation of the underlying factors in terms of the known stochastic processes, the process of verification can be accomplished. To a lesser degree, there also seems to be some extension of this concept to the process of validation. The following definitions of verification and validation are provided to support their intended meaning to this discussion (Pritsker, 1986: 11):

Verification: The process of establishing that the computer program executes as intended.

Validation: The process of establishing that a desired accuracy or correspondence exists between the simulation model and the real system.

As will be shown in Chapter IV, interpretations of the factor loadings matrices accurately reflected the coded processes of the simulation. In turn, these processes were able to be explained or related to real-world processes that normally occur in an airlift system. For a simulation model that has had no formal validation effort, these interpretations provided a type of verification and validation for AFM.

Since most of the selected performance variables were averages or functions of averages, the distributions of these variables were expected to be fairly normal due the central limit theorem (Mendenhall et al, 1990: 319). Therefore, multivariate normality was generally expected from this set of performance variables. Since the distributions of the variables should have been preserved during the transformation to the smaller set of factors, the distributions of the factors were also expected to resemble normal distributions. Therefore, plotting two factors on orthogonal axes should have presented a nice "shotgun pattern" representing a bivariate normal distribution. In this case, any pattern other than a single shotgun pattern indicated an unexpected violation of multivariate normality and possibly a quirk in the model.

## Define Perturbation Schemes

This section describes the perturbations made to the various parameters of the file 63 and explains the experimental design used. Ideally, the goal was to perturb the file 63 enough so that possible TPFDD variations were accounted for, but not so much that the perturbations became operationally unrealistic. For each line in the file 63 the following variables were perturbed according to an experimental design: aerial port of embarkation (APOE), aerial port of debarkation (APOD), available-to-load date (ALD), required delivery date (RDD), outsize tons, oversize tons, bulk tons, and numbers of passengers. Appendix D contains the FORTRAN code used to generate the perturbed files 63 for this research.

APOE and APOD Perturbation. The onload locations specified in a TPFDD can be considered uncertain because peacetime exercises and deployments move US forces

around the globe on a regular basis. In addition, recent military downsizing and consolidation of US forces to an ever smaller number of military bases further confounds the accuracy of onload locations in any TPFDD created before these recent changes were made. Offload locations can also change because the TPFDD never executes as planned. As was seen in Desert Shield/Storm, frequent changes to the TPFDD caused confusion as to where certain cargo and personnel were supposed to go (USGAO, 1993: 24-25).

Since all APOE/APOD pairs in the file 63 must have defined route segments and other supporting information in several other AFM input files, all APOE/APOD combinations used in the original file 63 were stored in a list, along with the great circle distance between the two points. For each line of the file 63, the APOE/APOD pair was swapped with a randomly selected pair from the saved list. Only those APOE/APOD pairs with a great circle distance within ten percent of the original distance were eligible for random selection. This perturbation changed the distribution of cargo and passengers around the network, but should have left the average ton-distance workload requirement about the same, providing a basis for comparison. This perturbation tests the model's sensitivity to varying distributions of cargo and passengers between the limited network resources.

<u>ALD and RDD Perturbation</u>. Historically, the priorities of the requirements and the actual cargo delivery schedule change frequently and end up being drastically different from the initial TPFDD (Lund et al, 1993: 24-25). In addition, the time schedule of onloads and offloads has been compromised since the TPFDD was first checked for gross transportation feasibility, because the primary way to make a TPFDD transportationally

feasible is to stretch out the timeline. The relative order of the majority of TPFDD requirements are probably pretty close to the original concept of operations, but the timeline most likely is not.

When scheduling missions in simulation time, AFM starts at the top of the file 63 and finds the first load that is compatible with the aircraft type that has an available-to-load date (ALD) equal to or less than the current simulation time. It is important to notice that AFM does not consider the required delivery date (RDD) during the simulation's execution. ALD is only considered to see if a line of cargo is eligible to be airlifted. Compared to all requirements with an ALD less than or equal to the current simulation time, the higher a requirement is in the file 63, the higher its priority. Therefore, the file 63 will be sorted by RDD to keep the earliest required delivery dates at the top of the list. The ALD/RDD perturbation scheme adds plus or minus one day to the ALD for each requirement, then adjusts the RDD to keep the number of allowable delivery days the same.

Because the AFM output variables selected were expected to be very sensitive to this perturbation, the maximum magnitude of the perturbation was kept fairly small (Shirley, 1995). For each line of the file 63, a randomly selected integer value of -1, 0, or 1 was added to the available-to-load date (ALD) and to the required delivery date (RDD). Negative values for ALD or RDD were reset to zero due to model restrictions. The perturbed lines were re-sorted by RDD, then by ALD, and then by a sequence number that reflected where the line was in the original sequence. This method of sorting kept all

the lines with the same new ALD and RDD in the same prioritized sequence as in the original file 63.

Load Strain Perturbation. The size of the task, in terms of tons of cargo and number of passengers, seems somewhat uncertain (Robinson, 1993: 7). Plausible changes in the nature of forces required for any given scenario (i.e. replacing light infantry with a mechanized brigade in some scenarios, or sending in Air Force interdiction units first instead of Marine units) can change total cargo and passenger requirements (Yost, 1995: 33). In such situations, the possibility of increasing the required amounts of cargo and the required rate of cargo deliveries seems likely. How much more can we strain the airlift system and still get reasonable performance? Can we get more performance?

For this perturbation scheme, the tonnage for each of the cargo categories and the number of passengers, for each requirement, were increased by ten percent. This increase in load requirement strained the airlift system by increasing the required rate and demand for deliveries.

Perturbing the Proportion of Outsize vs. Oversize Cargo. In addition to not knowing the exact size of each requirement, knowledge of pre-positioned supplies can change over time, invalidating some of the assumptions made during the TPFDD creation process. Under current pre-positioning assumptions, the proportions for the various categories of airlift cargo during the airlift surge period are roughly: 15% bulk cargo, 15% outsize cargo, and 70% oversize cargo (Schaefer, 1995). Figure 3-1 illustrates the actual proportions of the cargo categories for the two scenarios included in this research.

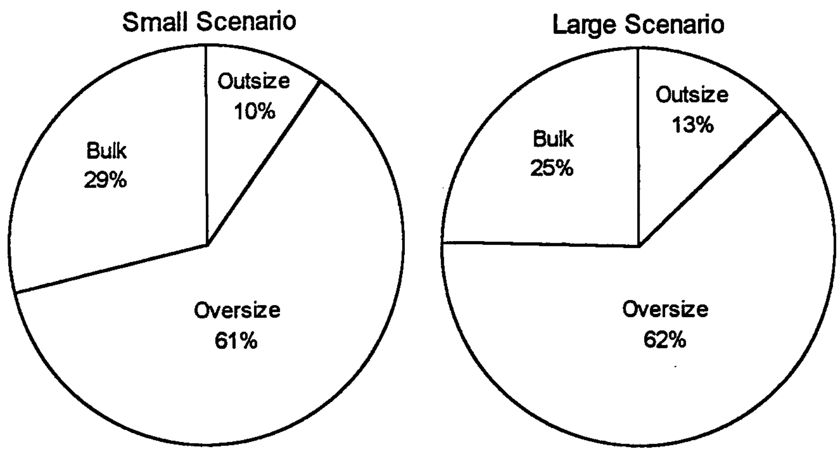


Figure 3-1. Surge Period Cargo Proportions for Research Scenarios.

Both scenarios show a larger proportion of bulk cargo and a lower proportion of oversize cargo than the expected rough proportions mentioned above, probably due arbitrary selection of the 30-day mark as the end of the surge period in this research. Current thoughts on changes to our national pre-positioning strategy almost double the amount of outsize cargo and subtract an equivalent tonnage from the oversize category (Schaefer, 1995). Therefore, for this perturbation scheme, the amount of outsize cargo in each line of the file 63 was doubled. An equivalent tonnage was subtracted from the oversize cargo value, and was carried over to subsequent lines, if necessary, to keep the total outsize plus oversize tonnage value constant.

Experimental Design. For the experimental design, each of these four perturbations was considered a deterministic effect. An orthogonal $2^{4-1}$ fractional factorial design was selected to allow for unbiased estimation of the effects of the four perturbation schemes, while also estimating the effects from the possible interaction of any two of these perturbation schemes (Box and Draper, 1987: 148-166). The design encompassed 8

runs, where the number of replications for each run was an input variable to the generation program (see Appendix D). Ten replications were actually conducted. During testing of the individual perturbation code segments, additional files 63 were created to validate the code. These files 63 were saved and added to the design, as design points 8 and 9, because they existed and they allowed for direct measurement of the two random effects. The design matrix is shown in Table 3-1, where 0 represents the effect being off, and 1 represents the effect being on. For example, all runs corresponding to design point 1 were made using a file 63 that was perturbed by both the load strain perturbation and the outsize/oversize proportion perturbation.

Table 3-1. Experimental Design for Evaluating TPFDD Perturbation Effects

| Design | TPFDD Perturbation Effects | | | |
|---|---|---|---|---|
| Point | APOE/APOD | ALD/RDD | Load Strain | Out/Over Proportion |
| 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 1 | 1 |
| 2 | 0 | 1 | 0 | 1 |
| 3 | 0 | 1 | 1 | 0 |
| 4 | 1 | 0 | 0 | 1 |
| 5 | 1 | 0 | 1 | 0 |
| 6 | 1 | 1 | 0 | 0 |
| 7 | 1 | 1 | 1 | 1 |
| 8* | 0 | 1 | 0 | 0 |
| 9* | 1 | 0 | 0 | 0 |
| *Not part of the original 24-1 factorial design, added after the fact | | | | |

<u>Analyze Sensitivities to Perturbations Using Factor Analysis</u>

Ten replications of each of the ten design points resulted in output from 100 AFM runs. Factor analysis techniques were used to reduce the dimensionality of the selected MOE's. For both the large and small scenarios, each of the resulting factors showed fairly straightforward interpretability and defined key areas of performance. The random seed

runs provided an interpretation reference for the factor loadings matrix from the perturbation runs. The interpretation of most factors repeated the logical groupings of the performance variables, as outlined at the beginning of this chapter. Since factors represent orthogonal and independent dimensions, the separation of the individual performance categories on separate factors indicated total airlift system performance was a nearly linear function of the independent contributions from each performance category.

Factor plots, labelled as "sensitivity plots" in this thesis, graphically showed the relative effects corresponding to each of the perturbations. Ten of the 50 random seed runs were included in this portion and served very well as a reference measure of the model's internal random noise, clearly identifying which perturbations were significant. Explanation of the relative sensitivities of both large and small scenarios provided further understanding of the internal processes of the AFM model.

# IV. Data Description and Analysis

## Introduction

This chapter presents the data developed and used in this thesis. A summary of the related analysis conducted on that data is also provided. Data and analysis of 50 runs, where the starting random seed value changed from run to run, are presented for both scenarios. The application of factor analysis to these random seed runs indicated potential for using factor analysis during verification and validation processes for large stochastic simulation models. After the section on the random seed run data, the data and analysis of 100 perturbation runs are presented. The application of factor analysis to these perturbation runs provided a unique sensitivity analysis tool. The resulting sensitivity plots graphically showed the impact of each of the experimental design points relative to the baseline performance measured in the random seed runs. The summary at the end of each section identifies the common links found between the two scenarios.

## File 63 Data

This section provides a summary of the two scenarios used during this research. Information on the small scenario is presented first, followed by the large scenario.

Small Scenario. The small scenario file 63 contains 1568 requirement lines which specify 75,854 tons of cargo and 139,480 passengers (pax) destined primarily for islands in the Caribbean. Table 4-1 presents a summary of the file 63 by listing the amount of cargo and number of pax for each aerial port of debarkation (APOD). The ICAO

their respective airfields. MOG, in the last column of Table 4-1, stands for maximum-on-the-ground, and represents a ground resource constraint where a MOG value of 1 is equivalent to the parking space required to park and service one C-141B sized aircraft within a specified time window. MOG is commonly used as a planning tool to reflect how many aircraft can simultaneously be on the ground at one airfield, and is often confused with parking spots available. However, the relationship between MOG and parking spots is not one-to-one because aircraft larger than a C-141B may require more than one MOG resource.

Table 4-1. Cargo and Passenger Destinations in Small Scenario

| Aerial Ports of Debarkation | ICAO | Cargo | Pax | MOG |
|---|---|---|---|---|
| Luis Munoz Marin Intl, San Juan | TJSJ | 30869 | 75847 | 7 |
| Norman Manley Intl/Kingston, Jamaica | MKJP | 17353 | 17527 | 5 |
| Montego Bay/Sangster, Jamaica | MKJS | 7208 | 13680 | 4 |
| Port au Prince, Haiti | MTPP | 6840 | 11540 | 2 |
| Great Inagua/Matthew Town, Bahamas | MYIG | 6223 | 6008 | 1 |
| George Town/Owen Roberts Intl, Cayman Is | MWCR | 2859 | 1001 | 2 |
| Roosevelt Roads NS, Puerto Rico | TJNR | 1504 | 2150 | 8 |
| Macdill AFB, Florida | KMCF | 771 | 991 | 2 |
| Key West NAS, Florida | KNQX | 625 | 179 | 2 |
| Homestead AFB, Florida | KHST | 534 | 838 | 2 |
| Hurlburt Field, Florida | KHRT | 295 | 193 | 2 |
| McGuire AFB, New Jersey | KWRI | 285 | 170 | 80 |
| Dyess AFB, Texas | KDYS | 231 | 249 | 20 |
| Tyndall AFB, Florida | KPAM | 145 | 103 | 2 |
| Eglin AFB, Florida | KVPS | 48 | 118 | 2 |
| Orlando Intl, Florida | KMCO | 44 | 139 | 2 |
| Moody AFB, Georgia | KVAD | 15 | 0 | 8 |
| Miami Intl, Florida | KMIA | 4 | 51 | 2 |
| Patrick AFB, Florida | KCOF | 0 | 16 | 2 |
| Warner Robins AFB, GA | KWRB | 0 | 10 | 42 |
| Charleston AFB/Muni, South Carolina | KCHS | 0 | 8607 | 54 |
| Jacksonville NAS, Florida | KNIP | 0 | 58 | 4 |
| Seymour Johnson AFB, Florida | KGSB | 0 | 5 | 8 |
| **TOTALS** | | 75854 | 139480 | 263 |

Notice that Table 4-1 is sorted in descending order of the total cargo tons value. The difficulty in delivering the cargo and passengers for this scenario can be identified by focusing on the first seven airfields. These first seven airfields receive 96% of the cargo and 92% of the passengers into a cumulative MOG value of 29, which is only 11% of the total MOG available at destinations in this scenario.

The small MOG values for the majority of the destination airfields in this scenario did prove to limit the overall airlift performance. For instance, the only aircraft in this scenario that prefers to carry passengers is the Boeing 747, which required a MOG of two in order to use an airfield. The C-5, C-141B, and C-17 aircraft carried passengers, but not nearly as efficiently; and only the C-141B or the C-17 could deliver passengers into an airfield with a MOG of one. Consequently, the arrival rate of passengers at Great Inagua (MYIG), with a MOG of one, was fairly low.

Large Scenario. The large scenario file 63 contains 431 requirement lines which specify 402,796 tons of cargo and 498,369 passengers (pax) destined primarily for the Middle East. Table 4-2 presents a summary of the file 63 by listing the amount of cargo and number of pax for each aerial port of debarkation (APOD). Notice that Table 4-2 is sorted in descending order of the total cargo tons value. Compared to the small scenario, the distribution of the cargo and passengers between the APODs is a little better. In the large scenario, for instance, 96% of the cargo and 91% of the passengers are received into the first six airfields in Table 4-2; but these six airfields have a cumulative MOG value of 50, which is 75% of the total MOG available. Though the overall distribution seems

better, one exception is the seemingly disproportionate values for cargo and pax destined for OEJB with a MOG value of 1.

Table 4-2. Cargo and Passenger Destinations in Large Scenario.

| Aerial Ports of Debarkation | ICAO | Cargo | Pax | MOG |
|---|---|---|---|---|
| Dhahran International | OEDR | 308228 | 306122 | 26 |
| Jubail Air Base | OEJB | 31079 | 81384 | 1 |
| King Khalid Military City | OEKK | 15642 | 31421 | 2 |
| Diego Garcia NSF | FJDG | 13560 | 3836 | 4 |
| Doha International | OTBD | 11548 | 21423 | 4 |
| King Abdul Azziz International | OEJN | 9205 | 6276 | 13 |
| Al Dhafra Air Base | OMAM | 5714 | 6474 | 4 |
| Bahrain International | OBBI | 5330 | 9272 | 4 |
| Seeb International | OOMS | 1490 | 4031 | 4 |
| Riyadh Military | OERY | 1000 | 28130 | 5 |
| **TOTALS** | | 402796 | 498369 | 67 |

Compared to the small scenario, the MOG values for most of the destination airfields in the large scenario are greater. The total cargo ton and passenger requirement is much larger than in the small scenario. Also, the average distance from in the U.S. to the destinations is much greater in the large scenario than the small scenario. Therefore, as opposed to the small scenario's preference for the performance of the smaller aircraft types, the large scenario was expected to benefit more from the larger, longer range aircraft types.

<u>Random Seed Run Data</u>

In considering how to determine if perturbations to the file 63 caused more variance than would be expected from the AFM stochastic processes, information on the effects of AFM's internal random processes on AFM output was desired as a baseline for comparison. Because there was no documentation as to how much variation can be

expected from the AFM simulation when the initial random seed is changed, the effects of changing the random seed on selected output variables was investigated as a prelude to the analysis of perturbation effects. The information in this section and in Appendices B and C provide the first known documentation of the effects of changing random seeds on AFM output. For both scenarios, 10 of the 50 runs conducted in this section were used as a reference basis for interpreting the perturbation effects, as shown in the next section. The analysis of the perturbation effects can stand on its own and does not explicitly rely on any information from this section. However, the information presented here provides insight into how the AFM random processes work, demonstrating how factor analysis might be used for stochastic simulation model verification and validation.

Small Scenario. Thirty-three measures of effectiveness were extracted from the AFM output for each of the 50 runs conducted. Of the 33 selected variables, 8 were discarded as unusable. The aircraft cycle time statistics were output as zero when there weren't enough cycles completed by the respective aircraft types. Only the C-17 and the C-141B aircraft seemed to complete enough cycles to generate non-zero cycle statistics for all 50 runs. Since the B-747P aircraft were not allowed to carry cargo in the simulation, the B-747P cargo statistics were zero for all 50 runs. The eight discarded variables were:

| | |
|---|---|
| C-5A f-cycle time | B-747P f-cycle time |
| C-5A g-cycle time | B-747P g-cycle time |
| KC-10 f-cycle time | B-747P average payload |
| KC-10 g-cycle time | B-747P MTM/D per aircraft |

The remaining 25 variables plus four injected random noise variables were analyzed iteratively, using PROC FACTOR in SAS with a VARIMAX rotation. Comparing the factor loadings of the 25 measures of effectiveness to the factor loadings of the 4 noise variables, three more variables could not be distinguished from random noise during this process, and were discarded along with the four injected noise variables:

| | |
|---|---|
| C-141B f-cycle time | % Shipments still open |
| C-17 f-cycle time | |

In addition, *MTM/D delivered* and *% Shipments late* were discarded because they were more than 99 percent correlated with *Total cargo tons delivered* and *% Shipments ontime*, respectively. There was concern that such a high degree of correlation between variables measuring the same type of performance would tend to bias the factor analysis results. The remaining 20 variables still sufficiently represented the areas of airlift performance to provide useful information. The measures of effectiveness studied for this scenario were:

| | |
|---|---|
| C-5A use rate | C-141B use rate |
| C-5A average payload | C-141B g-cycle time |
| C-5A MTM/D per aircraft | C-141B average payload |
| | C-141B MTM/D per aircraft |
| C-17 use rate | |
| C-17 g-cycle time | KC-10 use rate |
| C-17 average payload | KC-10 average payload |
| C-17 MTM/D per aircraft | KC-10 MTM/D per aircraft |
| B-747P use rate | Outsize tons delivered |
| | Passengers delivered |
| % Shipments ontime | Total cargo tons delivered |
| Average days late | |

Due to the large difference in magnitude between the variables, the correlation matrix was used instead of the variance-covariance matrix during factor analysis (see Equation 2).

When the variables under consideration are measured in different units, scale effects can influence the composition of the derived factors (Dillon and Goldstein, 1984: 36). In such cases, the data are standardized and the correlation matrix is used in place of the variance-covariance matrix (Dillon and Goldstein, 1984: 36). Appendix B contains the raw output data from the 50 runs conducted, plus summary statistics and the computed factor scores. As a summary of Appendix B, Table 4-3 presents the summary statistics for each of the 20 performance variables. The coefficient of variation is a statistical tool defined by dividing the standard deviation by the mean. The coefficients of variation are expressed as percentages and for 18 of the variables were at or below 2.5%. The number of each aircraft type is indicated in parentheses.

Table 4-3. Summary Statistics for Small Scenario Random Seed Runs.

| Performance Category | Variable | Mean | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|
| C-5A (28) | Use Rate | 2.3800 | 0.0571 | 2.4% |
| | Average Payload | 70.7858 | 0.3962 | 0.6% |
| | MTM/D | 0.0182 | 0.0004 | 2.4% |
| C-141B (56) | Use Rate | 8.2620 | 0.1383 | 1.7% |
| | G-Cycle Time | 11.4538 | 0.0861 | 0.8% |
| | Average Payload | 27.4190 | 0.1606 | 0.6% |
| | MTM/D | 0.0371 | 0.0006 | 1.5% |
| C-17 (15) | Use Rate | 10.7980 | 0.4068 | 3.8% |
| | G-Cycle Time | 14.4398 | 0.2791 | 1.9% |
| | Average Payload | 53.6086 | 0.8635 | 1.6% |
| | MTM/D | 0.0526 | 0.0039 | 7.4% |
| KC-10 (28) | Use Rate | 1.4180 | 0.1792 | 12.6% |
| | Average Payload | 41.6798 | 0.7252 | 1.7% |
| | MTM/D | 0.0050 | 0.0005 | 10.3% |
| B-747P (11) | Use Rate | 4.8760 | 0.0847 | 1.7% |
| Throughput | Outsize Tons | 7588.3600 | 39.6607 | 0.5% |
| | Pax | 56636.8000 | 361.8051 | 0.6% |
| | Cargo Tons | 72335.8400 | 1643.5637 | 2.3% |
| Timeliness | Percent Ontime | 84.4330 | 0.1045 | 0.1% |
| | Days Late | 0.6746 | 0.0065 | 1.0% |

The C-17 use rate and MTM/D variables had slightly higher coefficients of variation, probably due to the fact that there are so few of them in this scenario, relative to the numbers of other cargo aircraft. Randomly selecting one C-17 out of 15 will have a greater effect on its use rate than randomly selecting one C-5 or C-141B out of the 28 or 56 aircraft, respectively, in the scenario.

The KC-10 use rate and MTM/D variables have the highest coefficients of variation. These two variables also probably suffer from an effectively small number of aircraft. Though there are 28 KC-10's in the small scenario, they are not introduced until day 13, equating to just under 17 aircraft available per day when averaged over the full 30-day period. In addition, the magnitudes of the mean values for the KC-10 use rate and MTM/D were relatively small values, where any measurable change was a significant percentage of the mean value.

Factor analysis reduced dimensionality of the data from 20 inter-related variables to 5 independent factors, as shown in Table 4-4. Since the factor analysis model attempts to account for as much of the total variance in the data as possible by identifying common variance between the variables, the amount of total variance accounted for by the model is an indicator of the goodness of the model. In this case, common variance between the variables, caused by the five unknown factors, accounts for 71.9% of the total variance. The portion of common variance accounted for by each of the five factors is listed at the bottom of Table 4-4.

Table 4-4. Small Scenario Factor Loadings Matrix from 50 Random Seed Runs.

| Factor | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| C-5A use rate | -0.063 | 0.315 | **0.820** | -0.058 | -0.134 |
| C-5A average payload | -0.108 | 0.085 | 0.094 | 0.022 | **0.752** |
| C-5A MTMs/aircraft/day | -0.050 | 0.230 | **0.882** | -0.184 | 0.082 |
| C-141B use rate | **0.867** | -0.062 | -0.112 | 0.102 | 0.206 |
| C-141B g-cycle time | 0.240 | -0.088 | -0.022 | 0.025 | **0.405** |
| C-141B average payload | -0.179 | 0.121 | **-0.676** | -0.154 | -0.308 |
| C-141B MTMs/aircraft/day | **0.855** | 0.008 | -0.355 | -0.068 | 0.011 |
| C-17 use rate | **0.854** | 0.098 | 0.083 | -0.046 | 0.157 |
| C-17 g-cycle time | **-0.738** | -0.201 | -0.111 | -0.033 | 0.071 |
| C-17 average payload | **0.710** | -0.406 | -0.216 | 0.174 | -0.097 |
| C-17 MTMs/aircraft/day | **0.946** | 0.088 | 0.086 | 0.072 | 0.096 |
| KC-10 use rate | 0.171 | **0.917** | 0.206 | 0.016 | -0.087 |
| KC-10 average payload | 0.018 | **-0.605** | 0.084 | 0.481 | -0.240 |
| KC-10 MTMs/aircraft/day | 0.183 | **0.852** | 0.219 | 0.185 | -0.098 |
| B-747P use rate | 0.099 | 0.111 | 0.224 | **-0.562** | -0.292 |
| Outsize tons delivered | 0.372 | -0.050 | 0.139 | -0.245 | **0.558** |
| Passengers delivered | **0.905** | 0.104 | 0.174 | -0.009 | 0.085 |
| Total cargo tons delivered | **0.967** | 0.173 | 0.102 | 0.028 | 0.089 |
| % Shipments ontime | -0.062 | -0.053 | -0.034 | **-0.720** | 0.078 |
| Average days late | 0.099 | 0.059 | -0.003 | **0.828** | -0.068 |
| Eigenvalue | 6.2425 | 2.4011 | 2.3369 | 1.9620 | 1.4382 |
| Common Variance (%) | 43.4% | 16.7% | 16.3% | 13.6% | 10.0% |

The five factors described in Table 4-4 are variables, containing most of the information from all 20 original performance variables. Each of the 50 runs can now be represented by five values, called factor scores, that are computed from its 20 corresponding performance values. Factor scores for each run are included in Appendix B. The significance of the actual numeric value of a particular factor score can be best understood by interpreting the relationships between that factor and the performance variables, as shown in the factor loadings matrix. Since each loading value is a correlation coefficient between one factor and one performance variable, interpretation stems from identifying which variables are most highly correlated with the individual

factors. Loadings highlighted in Table 4-4 with a bold box were the largest values for their respective rows and were considered significant loadings.

By looking at Table 4-4, one of the interesting results was how the factor loadings tended to cluster by the type of performance measure (as described in Chapter III): aircraft, throughput, or timeliness. These loading clusters conveniently aided interpretation, relating most factors to the performance of one or two individual aircraft types. Only those variables with loadings greater than 0.500 (there is one exception) were used to interpret and label each of the factors as a performance index. Insight into how AFM's stochastic processes, particularly mission execution, affect AFM output can be interpreted from the relationships between variables that load on the same factor.

### *Factor 1. C-17/C-141B and General Throughput Index.*

- ***Significance***: In general, a high factor 1 score reflects: high cargo and passenger throughput, high C-17 performance, and high C-141B performance.

- ***Insight***: Most of the variance in cargo and passenger throughput values can be explained by AFM's more frequent use of C-17 and C-141B aircraft over other aircraft types. The cause of this more frequent use is the result of randomly drawing shorter flight and ground times for these aircraft types during execution, allowing them to be scheduled more frequently. Selection of aircraft for mission scheduling in AFM is first-in first-out, depending on when the aircraft enter the AFM mission scheduler's queue. Aircraft enter this queue after completing a mission and after a random ground time. Runs that have a high factor 1 score processed C-17 and C-141B aircraft more frequently than those runs with low factor 1 scores. Opposite signs are typically called "contrasts" in factor analysis. The C-17 g-cycle time contrast with the positive performance variables makes sense because the less time a C-17 sits on the ground, the more cargo and passengers it can move. An interesting peculiarity that shows up here is the apparent positive correlation between C-141B use rate and C-17 use rate, without any indicated competition for MOG or cargo. In reality, the C-17 can carry everything the C-141B can, but more efficiently. So, a higher C-17 use rate should typically mean a lower C-141B use rate. This peculiarity is important because it led to the unexpected discovery of correlated bi-modal distributions for these two

variables. Even more unexpectedly, this bi-modal characteristic applied to all eight variables which load highly upon this factor. Discussion of this "bi-modal problem" is pursued later in this section.

***Factor 2. KC-10 Index.***

- ***Significance***: In general, a high factor 2 score reflects high KC-10 performance.

- ***Insight***: Unrelated to throughput measures primarily due to the fact that KC-10's are not available until day 13 of the scenario. Since output statistics were measured at day 30, KC-10's had a limited time to contribute significantly to the overall throughput performance. Further limiting their contributions to throughput performance, over 70% of the bulk cargo had already been delivered before the first KC-10's were available, so there wasn't much bulk cargo left for the KC-10's to carry.

***Factor 3. C-5A/C-141B Oversize and Bulk Cargo Contrast.***

- ***Significance***: In general, a high factor 3 score reflects high C-5 use and low C-141B payloads. Conversely, a low factor 3 score reflects greater C-141B payloads and less C-5 use.

- ***Insight***: Since C-5 and C-141B aircraft shared the capability to carry oversize and bulk cargo, this factor reflects a sort of competition for which aircraft type carried this common cargo. Since there was a finite amount of cargo, those runs where C-5 aircraft were used more, they carried more cargo and left the C-141B aircraft with less to carry. In those runs with a high factor 3 score, C-5 use rate and MTM/D were high, causing a reduction in C-141 payload. In runs with low factor 3 scores, C-141B aircraft were flying with greater payloads and C-5 use rates were lower.

***Factor 4. Lateness Index.***

- ***Significance***: A high factor 4 score reflects more late deliveries and low B-747P use. A low factor 4 score reflects more timely deliveries and high B-747P use.

- ***Insight***: This factor was interpreted as a lateness index instead of a timeliness index because the late variable was positive. In general, it seems that variations in lateness (timeliness) were fairly independent of the variations in the types of aircraft selected for each line of cargo and independent of the variations in overall throughput. The exception obviously was the B-747P aircraft, which were configured to carry only passengers. B-747P aircraft carried a large majority of the passengers in this scenario. The variance in the lateness seems to be somewhat explained by B-747P usage because all the aircraft types were being used more efficiently by carrying what they were designed to carry. More specifically, runs

that used the B-747P more led to more timely deliveries because they freed up the other aircraft for cargo only. Military cargo planes were not built for pax and don't deliver them as efficiently as the B-747P.

*Factor 5. C-5A Outsize Index.*

- ***Significance***: In general, a high factor 5 score reflects greater use of C-5 aircraft to carry outsize cargo.

- ***Insight***: Since C-5s carried the majority of the outsize cargo in this scenario, it makes sense that variations in C-5 payloads affected the variations in outsize cargo throughput. For most bases in this small scenario, C-5 aircraft were realistically modeled to take 1.5 to 2.0 C-141B equivalent MOG resources. Larger payloads on the C-5 meant longer ground times, in general, affecting the number of C-141B aircraft that could obtain service or park at the same airports. The weak competition indicated (C-141B ground cycle times increase with increasing C-5 payloads) seems to reflect the competition between these two aircraft for airport resources (parking, servicing, etc.). This competition did not affect the other aircraft types as much because of the relatively large numbers of C-5 and C-141B aircraft in this scenario.

Another productive method of using factor analysis to understand the effects of AFM's internal random seed was plotting all 50 runs on factor by factor plots (i.e. a plot of factor 2 scores by factor 1 scores). Since the first two factors accounted for most of the total variance, they also provided the most information about the model.

Most of the 20 performance variables were averages or functions of averages, and the distribution of these variables were expected to be fairly normal due to the Central Limit Theorem (Mendenhall et al, 1990: 319). Though multivariate normality is not a requirement for a data set when using factor analysis, it was generally expected from this set of performance variables. Since the distributions of the variables should have been preserved during the transformation to the smaller set of factors, the distributions of the factors were also expected to resemble normal distributions. Therefore, plotting two

factors on orthogonal axes should have presented a nice "shotgun pattern" representing a bivariate normal distribution. In this case, any pattern other than a single shotgun pattern indicated an unexpected violation of multivariate normality.

Factor 1 scores were, in fact, distinctly bi-modal and non-normal, as can be seen in Figure 4-1. Plots of any of the other factors against factor 1 showed a similar breakout of the data into two distinct groups. The first question investigated was whether or not this bi-modal split was statistically significant. A statistical T-test, at the 0.05 significance level, for equal means between the two groups of factor 1 scores indicated that the split was indeed statistically significant. Furthermore, similar T-tests on all 8 variables that have high loadings on factor 1 had the same result. Indicating two statistically distinct groups within the fifty runs.

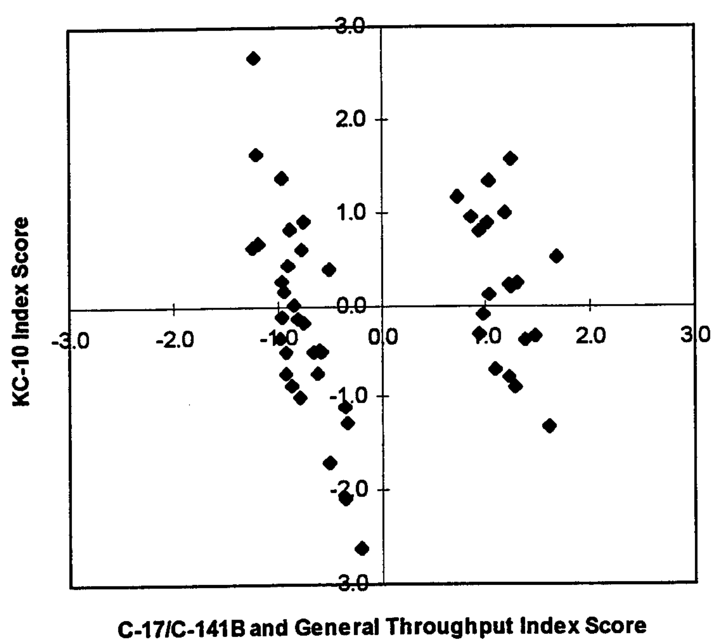


Figure 4-1. Plot of Factor 2 Scores by Factor 1 Scores (Small Scenario)

The next question investigated was the significance of the magnitude of the split. Since the factor scores are standardized values by their computation, a factor score of 1.0 would indicate the equivalent of one standard deviation. The means of the two groups, in terms of their factor 1 score, are separated by approximately 2.0. This equivalent of two standard deviations was considered significant. Looking back at the coefficients of variation for the eight variables that load on factor 1 (see Table 4-3), a two standard deviation split equates to less than 5% of the mean values. Though statistically significant, the question of practical significance of a 5% split in any of these variables arose. AMCSAF considered this split to be practically insignificant, but nonetheless important to a better understanding of their model (Hagin, 1996).

Further investigations into the cause of this bi-modal split point to the model's mission scheduling heuristic as a possible source. In particular, when the mission scheduler attempts to match a cargo load to an available aircraft, there is a minimum amount of cargo that is considered too small, or too trivial, to dispatch an aircraft to get that cargo. This minimum amount of cargo is defined as the aircraft's *trivial load limit.* Cargo that is below the trivial load limit for all aircraft basically gets ignored by the AFM simulation. There is a trivial load collection heuristic included in the version of AFM used for this research that attempts to correct for this deficiency in the model, but apparently, it did not work well for 31 of the 50 runs conducted. The trivial load collection heuristic attempts to fill any aircraft that has unused payload capacity, only if it has first found a non-trivial load. A large majority of requirement lines in the small scenario file 63 are trivial for the larger aircraft. Even for the C-141B, which has the smallest trivial load limit

of 7 tons, there were over 300 lines that would not be picked up directly by dispatching a C-141B aircraft. To illustrate, Figure 4-2 shows a plot of total cargo delivered over time from one run on each side of this bi-modal split. The two runs seem to be fairly equal until about day 24, when one run essentially delivered the last line of cargo and totaled only 71000 tons. The other run continues to deliver cargo for about 3 more days because it did a better job of collecting trivial loads over the first 24 days and has more cargo to deliver.

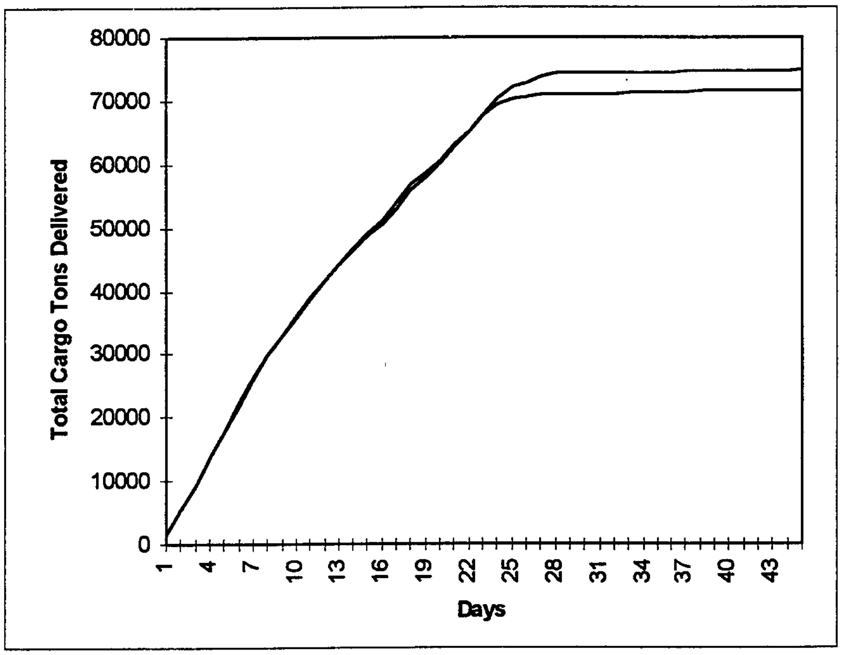


Figure 4-2. Plot of Total Cargo Tons Delivered Over Time for Two Selected Runs

Considering that the group of runs on the high side of the split had more C-141B deliveries than the group on the low side, the mission scheduler dispatched aircraft to more lines of cargo because the C-141B had the smallest trivial load limit. In these cases, the mission scheduler also had more opportunity to collect trivial loads because each time

an aircraft was dispatched to a cargo requirement, any unfilled payload capacity on that aircraft was an opportunity for a trivial load somewhere nearby. The group of 31 runs on the low side of the split had more widebody aircraft making deliveries than the group of 19 runs on the high side. With more widebody aircraft making deliveries, there were fewer opportunities for trivial cargo to be collected and greater opportunities for cargo requirements to be considered trivial.

Based on these observations, the AFM mission scheduling heuristic seems to be incompatible with the detailed structure of the file 63 provided with the small scenario. This file 63 divides a fairly small amount of cargo into approximately 1500 requirement lines, where many lines were small enough to be delivered only as trivial loads with the trivial load collection heuristic, if they were delivered at all by the AFM simulation.

Large Scenario. Forty three measures of effectiveness were extracted from the AFM output for each of the 50 runs conducted. Of the 43 selected variables, 2 were output from AFM as zero for all 50 runs and were discarded:

| | |
|---|---|
| B-747P average payload | B-747P MTM/D per aircraft |

The remaining 41 variables plus four injected random noise variables were analyzed iteratively, using PROC FACTOR in SAS with a VARIMAX rotation. Comparing the factor loadings of the 41 measures of effectiveness to the factor loadings of the noise variables, 8 more variables could not be distinguished from random noise during this process, and were discarded along with the 4 injected noise variables:

| | |
|---|---|
| C-5 f-cycle time | C-141B f-cycle time |
| C-17 f-cycle time | KC-10 f-cycle time |
| DC-8 f-cycle time | B-747 f-cycle time |
| B-747P f-cycle time | % Shipments still open |

In addition, *MTM/D delivered* and *% Shipments late* were discarded because they were more than 99 percent correlated with *Total cargo tons delivered* and *% Shipments ontime*, respectively. There was concern that such a high degree of correlation between variables measuring the same type of performance would tend to bias the factor analysis results. The remaining 31 variables still sufficiently represented the areas of airlift performance to provide useful information. The measures of effectiveness studied for this scenario were:

C-5A use rate
C-5A g-cycle time
C-5A average payload
C-5A MTM/D per aircraft

C-141B use rate
C-141B g-cycle time
C-141B average payload
C-141B MTM/D per aircraft

C-17 use rate
C-17 g-cycle time
C-17 average payload
C-17 MTM/D per aircraft

KC-10 use rate
KC-10 g-cycle time
KC-10 average payload
KC-10 MTM/D per aircraft

B-747 use rate
B-747 g-cycle time
B-747 average payload
B-747 MTM/D per aircraft

DC-8 use rate
DC-8 g-cycle time
DC-8 average payload
DC-8 MTM/D per aircraft

B-747P use rate
B-747P g-cycle time

Outsize tons delivered
Passengers delivered
Total cargo tons delivered

% Shipments ontime
Average days late

As in the small scenario, due to the large difference in magnitude between the variables, the correlation matrix was used during factor analysis. Appendix C contains the raw output data from the 50 runs conducted, plus summary statistics and the computed factor scores. Table 4-5 presents the summary statistics from Appendix C. In this case, the

coefficients of variation for all 31 variables were at or below 2.9%. The number of each aircraft type available to this scenario is indicated in parentheses.

Table 4-5. Summary Statistics for Large Scenario Random Stream Runs.

| Performance Category | Variable | Mean | Standard Deviation | Coefficient of Variation |
|---|---|---|---|---|
| C-5A (95) | Use Rate | 10.9300 | 0.0463 | 0.4% |
| | G-Cycle Time | 42.4572 | 0.1918 | 0.5% |
| | Average Payload | 60.1660 | 0.9441 | 1.6% |
| | MTM/D | 0.1196 | 0.0019 | 1.6% |
| C-141B (75) | Use Rate | 12.4040 | 0.0832 | 0.7% |
| | G-Cycle Time | 33.5337 | 0.4602 | 1.4% |
| | Average Payload | 20.6706 | 0.2348 | 1.1% |
| | MTM/D | 0.0425 | 0.0004 | 1.0% |
| C-17 (51) | Use Rate | 14.6780 | 0.0679 | 0.5% |
| | G-Cycle Time | 23.0392 | 0.3829 | 1.7% |
| | Average Payload | 42.9998 | 0.4856 | 1.1% |
| | MTM/D | 0.1126 | 0.0013 | 1.2% |
| KC-10 (37) | Use Rate | 12.6220 | 0.0764 | 0.6% |
| | G-Cycle Time | 29.4185 | 0.3921 | 1.3% |
| | Average Payload | 33.8134 | 0.9073 | 2.7% |
| | MTM/D | 0.0898 | 0.0025 | 2.8% |
| B-747 (60) | Use Rate | 9.4100 | 0.0647 | 0.7% |
| | G-Cycle Time | 36.4595 | 0.4470 | 1.2% |
| | Average Payload | 65.0894 | 0.4501 | 0.7% |
| | MTM/D | 0.1245 | 0.0015 | 1.2% |
| B-747P (90) | Use Rate | 9.5060 | 0.1202 | 1.3% |
| | G-Cycle Time | 46.1696 | 0.9782 | 2.1% |
| DC-8 (40) | Use Rate | 9.3860 | 0.1429 | 1.5% |
| | G-Cycle Time | 36.0512 | 1.0513 | 2.9% |
| | Average Payload | 17.3942 | 0.1517 | 0.9% |
| | MTM/D | 0.0317 | 0.0008 | 2.6% |
| Throughput | Outsize Tons | 12790.3200 | 266.9268 | 2.1% |
| | Pax | 168470.9000 | 3289.5428 | 2.0% |
| | Cargo Tons | 119970.7600 | 708.3134 | 0.6% |
| Timeliness | Percent Ontime | 14.9680 | 0.1407 | 0.9% |
| | Days Late | 2.5072 | 0.0168 | 0.7% |

Factor analysis reduced dimensionality of the data from 31 inter-related variables to 10 independent factors. In this case, common variance between the variables, caused by the ten unknown factors, accounts for 82.5% of the total variance. As in the small

scenario, the patterns of relationships between variables shown in Table 4-6 contributed to understanding AFM's stochastic processes during execution of the large scenario.

Table 4-6. Large Scenario Factor Loadings Matrix.

| Factor | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| C-5A use rate | **0.50** | -0.16 | -0.06 | 0.37 | -0.15 | 0.26 | -0.27 | -0.20 | -0.08 | -0.11 |
| C-5A g-cycle time | -0.16 | **0.47** | -0.16 | 0.02 | 0.00 | -0.41 | 0.30 | 0.04 | -0.09 | -0.36 |
| C-5A average payload | **0.84** | 0.09 | 0.12 | 0.07 | 0.00 | -0.42 | 0.10 | -0.09 | 0.05 | 0.04 |
| C-5A MTMs/aircraft/day | **0.87** | -0.06 | 0.11 | 0.17 | 0.01 | -0.33 | -0.03 | -0.13 | 0.05 | 0.03 |
| C-141B use rate | 0.23 | -0.09 | 0.02 | 0.02 | -0.09 | -0.11 | -0.06 | **-0.85** | -0.12 | -0.16 |
| C-141B g-cycle time | 0.08 | -0.10 | -0.12 | 0.00 | -0.02 | 0.03 | 0.01 | **0.93** | -0.05 | 0.08 |
| C-141B average payload | **-0.50** | 0.09 | 0.05 | -0.14 | -0.03 | **0.70** | 0.03 | 0.21 | 0.18 | 0.04 |
| C-141B MTMs/aircraft/day | -0.28 | 0.28 | 0.06 | 0.11 | -0.13 | **0.73** | 0.13 | -0.13 | 0.13 | 0.05 |
| C-17 use rate | 0.32 | **-0.75** | -0.02 | -0.11 | 0.00 | 0.14 | 0.09 | 0.31 | 0.00 | -0.04 |
| C-17 g-cycle time | -0.25 | **0.75** | 0.04 | 0.22 | 0.16 | -0.12 | -0.02 | -0.26 | 0.04 | -0.04 |
| C-17 average payload | -0.08 | -0.17 | -0.10 | **-0.54** | 0.29 | **0.61** | 0.02 | 0.27 | -0.07 | -0.07 |
| C-17 MTMs/aircraft/day | -0.13 | -0.07 | -0.12 | **-0.55** | 0.29 | **0.62** | -0.07 | 0.28 | -0.09 | -0.04 |
| KC-10 use rate | 0.19 | **0.79** | -0.06 | 0.00 | -0.09 | 0.28 | -0.08 | 0.19 | 0.01 | 0.13 |
| KC-10 g-cycle time | -0.25 | **-0.83** | 0.02 | 0.01 | 0.09 | -0.16 | 0.14 | -0.21 | 0.06 | 0.04 |
| KC-10 average payload | 0.15 | 0.02 | -0.09 | **0.94** | 0.07 | -0.08 | 0.00 | 0.00 | -0.03 | -0.01 |
| KC-10 MTMs/aircraft/day | 0.19 | 0.18 | -0.08 | **0.92** | 0.04 | -0.01 | -0.02 | 0.08 | -0.01 | -0.07 |
| B-747 use rate | 0.10 | -0.13 | 0.06 | 0.10 | -0.11 | -0.02 | **0.81** | 0.10 | 0.09 | -0.23 |
| B-747 g-cycle time | -0.12 | 0.30 | -0.10 | 0.00 | 0.19 | 0.04 | **-0.69** | -0.02 | -0.13 | 0.01 |
| B-747 average payload | 0.04 | 0.25 | -0.06 | -0.01 | 0.16 | 0.16 | **0.48** | -0.01 | -0.44 | **0.55** |
| B-747 MTMs/aircraft/day | 0.10 | 0.12 | -0.06 | -0.17 | 0.17 | 0.14 | **0.81** | -0.06 | -0.26 | 0.23 |
| B-747P use rate | 0.08 | -0.05 | **0.95** | -0.05 | 0.12 | 0.02 | 0.11 | -0.05 | 0.02 | -0.02 |
| B-747P g-cycle time | -0.11 | 0.02 | **-0.93** | 0.04 | -0.03 | 0.03 | -0.11 | 0.12 | -0.09 | 0.07 |
| DC-8 use rate | -0.04 | -0.03 | 0.13 | -0.02 | **0.92** | 0.00 | 0.00 | -0.03 | 0.07 | -0.01 |
| DC-8 g-cycle time | -0.13 | -0.02 | -0.13 | -0.07 | **-0.85** | 0.04 | -0.04 | -0.01 | 0.00 | 0.22 |
| DC-8 average payload | 0.17 | 0.10 | -0.09 | -0.04 | 0.29 | -0.04 | -0.02 | -0.12 | **0.75** | 0.07 |
| DC-8 MTMs/aircraft/day | -0.10 | -0.03 | 0.05 | -0.06 | **0.79** | 0.10 | -0.19 | 0.11 | 0.31 | 0.21 |
| Outsize tons delivered | **0.80** | -0.02 | -0.06 | -0.03 | -0.10 | -0.10 | 0.20 | 0.13 | 0.04 | -0.06 |
| Passengers delivered | -0.08 | 0.02 | **0.92** | -0.03 | 0.13 | 0.01 | -0.14 | 0.01 | -0.01 | 0.00 |
| Total cargo tons delivered | **0.84** | 0.01 | 0.06 | 0.31 | 0.19 | 0.13 | 0.14 | -0.03 | -0.07 | 0.07 |
| % Shipments ontime | -0.13 | -0.10 | 0.18 | 0.02 | 0.06 | 0.21 | 0.04 | 0.18 | **0.67** | -0.10 |
| Average days late | -0.02 | -0.03 | -0.08 | -0.04 | -0.10 | -0.03 | -0.07 | 0.23 | 0.01 | **0.82** |
| Eigenvalues | 3.97 | 3.07 | 2.87 | 2.75 | 2.73 | 2.59 | 2.39 | 2.28 | 1.52 | 1.42 |
| Common Variance (%) | 15.5% | 12.0% | 11.2% | 10.7% | 10.7% | 10.1% | 9.3% | 8.9% | 5.9% | 5.5% |

***Factor 1. C-5 and Cargo Throughput Index.***

- ***Significance***: In general, a high factor 1 score reflects high cargo throughput and high C-5 payload/MTM performance.

- ***Insight***: Most of the variance in cargo throughput values can be explained by AFM's more frequent scheduling of C-5 aircraft over other aircraft types. The contrast between C-5 payloads and C-141B payloads is understandable since both aircraft compete for similar cargo. Accounting for the largest portion of common variance, this factor reflects this scenario's preference for a large, long-range cargo aircraft.

***Factor 2. C-17 and KC-10 Contrast.***

- ***Significance***: In general, high factor 2 scores reflect high KC-10 use and high C-17 ground cycle times. Conversely, low factor 2 scores reflect high C-17 use and high KC-10 ground cycle times.

- ***Insight***: This factor reflects competition between these two aircraft types for MOG resources and bulk cargo. There was also the possibility for competition between these two aircraft for oversize cargo, but since oversize cargo was not preferred by the KC-10, in the model, this possibility seemed remote.

***Factor 3. B-747P and Passenger Throughput Index.***

- ***Significance***: In general, high factor 3 scores reflect high passenger throughput performance and high B-747P use.

- ***Insight***: B-747 aircraft were designed to carry passengers, and they do it well. Almost all of the variation in passenger throughput in this scenario is accounted for by variations in B-747P performance. As in the first factor, the large scenario's preference for large, long-rang aircraft is also indicated here.

***Factor 4. KC-10 Throughput Index.***

- ***Significance***: In general, a high factor 4 score reflects high KC-10 throughput performance.

- ***Insight***: Increased KC-10 payloads were directly related to increased KC-10 MTM/D, which is not always the case, as evidenced by Factor 2 in Table 4-5 from the small scenario analysis. There was also an apparent contrast with C-17 throughput performance, indicating a competition for cargo.

***Factor 5. DC-8 Index.***

- ***Significance***: In general, a high factor 5 score reflects high DC-8 performance.

- ***Insight***: Increased use of DC-8 aircraft increased DC-8 MTM/D performance overall. The contrast with ground cycle times is understandable.

*Factor 6. C-17 and C-141B Throughput Index.*

- ***Significance***: High factor 6 scores reflects high C-17 and C-141B throughput.

- ***Insight***: Similar to the small scenario, the C-17 and C-141B seemed to work in concert instead of in competition. Since C-17 and C-141B aircraft carry the same cargo, it would have seemed more reasonable if there were some indication of competition for cargo or resources. This could be the result of a MOG tradeoff with the larger aircraft because each C-5 and B-747 require twice the MOG of the C-17 or C-141B. This could also be a repetition of similar phenomena as found in the small scenario, presenting even more evidence of a possible quirk in the model that favors the aircraft with the smaller trivial load limits.

*Factor 7. B-747 Index.*

- ***Significance***: In general, high factor 7 scores reflect high B-747 performance.

- ***Insight***: Increased B-747 use rates were positively correlated with increased MTM/D, and negatively correlated with B-747 ground cycle times.

*Factor 8. C-141B Ground Cycle and Use Rate Contrast.*

- ***Significance***: In general, high factor 8 scores reflect low C-141B use and high C-141B ground cycle times.

- ***Insight***: This factor inversely reflects the amount of flying accomplished by the C-141B fleet in this scenario.

*Factor 9. DC-8 Payload and Timeliness Index.*

- ***Significance***: In general, a high factor 9 score reflects high DC-8 payloads and more timely deliveries.

- ***Insight***: This is the first of two timeliness performance indices for this scenario, both of which relate timeliness of cargo deliveries to civilian aircraft performance. For large scale deployments, such as the one modeled in this scenario, the civil reserve air fleet (CRAF) is critical to success in delivering cargo on-time. In this case, the positive correlation between DC-8 payloads and timeliness of deliveries makes some sense.

*Factor 10. B-747 Payload and Lateness Index.*

- ***Significance***: In general, a high factor 10 score reflects greater B-747 payloads and more late deliveries.

- ***Insight***: This is the second of two timeliness indices that point toward variations in CRAF payloads as the main reason for variations in timelines or lateness. In this case, though, B-747 payloads alone appear to be positively correlated with increased lateness of deliveries. This relationship was unexpected because the B-747 is normally a very efficient long-range cargo aircraft. This relationship is so counterintuitive that it could lead to suspecting the methodology of interpretation, however, possible tradeoffs between payload and fuel as a result of routing decisions provided the best explanation (Hagin, 1996). More fuel and less payload would allow the B-747 to fly further and more directly without stopping, possibly increasing the rate of cargo deliveries and improving the overall timeliness of the deliveries.

For this scenario, the factor by factor plots were more in line with the multivariate normality expectation discussed earlier in the small scenario random seed analysis. The first two factors are plotted in Figure 4-3, and present a more normal bivariate distribution than was seen in Figure 4-1. A similar plot resulted when selecting any two factors from the large scenario random seed runs.

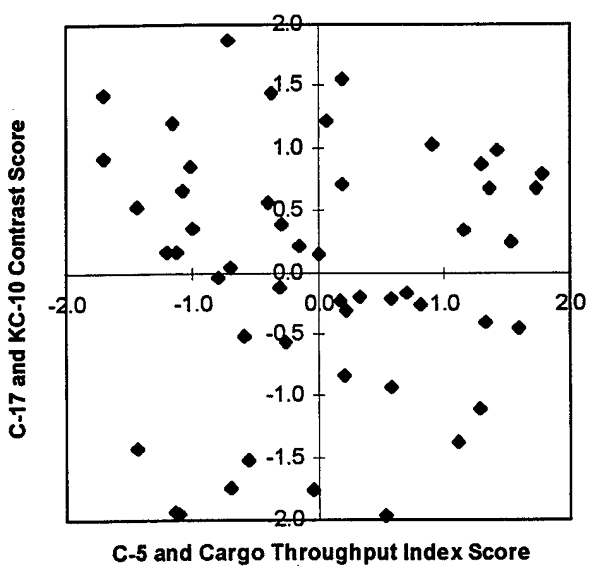


Figure 4-3. Plot of Factor 2 Scores by Factor 1 Scores (Large Scenario)

Potential for Verification and Validation. As mentioned in Chapter II, the factor analysis model attempts to account for variation in the original data by identifying common factors that cause the variation. By changing only the initial random seed from run to run, the cause, or source, of the variation in output variables is attributable only to the simulation's internal stochastic processes that depend on the initial random seed. Therefore, the factor model should reflect the model's internal stochastic processes.

In this case, the factor scores reflected the result of the stochastic mission execution process in the AFM. When one aircraft type drew shorter ground times, it got scheduled more frequently, delivered more cargo, and used more MOG resources. In the small scenario, an almost chaotic result occurred due to small changes in the types of aircraft that made more frequent deliveries. In general, from the *verification* standpoint, the model seems to be working as designed. The exception, of course, being the trivial load collection heuristic and its relation to the mission scheduling heuristic.

Variable relationships were also interpreted from the factor loadings matrix in terms of processes that could occur in the real world airlift system. Though there was no direct comparison to actual airlift system processes during execution of similar TPFDDs, there seems to be some potential here for model *validation*, as well.

Summary of Random Seed Runs. AFM's internal random seed affected the variance of AFM output variables. Variation for most AFM output variables was reflected in coefficients of variation, which did not normally exceed 3% of the mean values. Some variables in the small scenario exhibited a tendency toward a bi-modal distribution.

Factor analysis was helpful in reducing dimensionality of the data and in gaining insight into how AFM output was affected by changing the random seed. Factor loadings matrices indicated how AFM's stochastic processes had independent affects on performance characteristics of the individual aircraft types. In turn, overall characteristics of the airlift system itself seemed to be a nearly linear function of performance characteristics of the individual aircraft types. Competition for resources and cargo were also reflected, when significant to changes in performance. Interpretations of the factor loadings matrix tended to mirror real world processes, with the exception of the bi-modal problem noted in the small scenario. This reflection of real world processes seemed to further validate AFM as a useful airlift model.

The investigation into random seed effects basically treated AFM as a black box, and focused on AFM output variables using factor analysis to characterize the inner workings of the black box. In this sense, this application of factor analysis to characterize a stochastic simulation demonstrated potential for model verification and validation.

<u>Perturbation Run Data</u>

Perturbations to the two original files 63 were accomplished using the FORTRAN program listed in Appendix D. This FORTRAN code was used to generate ten file 63 perturbations for each of the design points 1 through 7, as discussed in Chapter III (see Table 3-1). Ten of the 50 random seed runs from the previous section were used for design point 0. As mentioned in Chapter III, during the development and testing of the FORTRAN code, test runs were made that generated additional useful perturbations of the file 63. Because these file 63's were available, they were included in the design as

design points 8 and 9. With 10 runs at each design point, output from 100 AFM runs was analyzed during this portion of the research. After computing the factor scores for each run, plotting each of the 100 runs on factor by factor plots provided a graphical tool for sensitivity analysis.

Small Scenario. Appendix E contains the raw AFM output data for the 100 runs used. Using the SAS procedure, PROC FACTOR with a VARIMAX rotation, on this data set resulted in the factor loadings matrix presented in Table 4-7.

Table 4-7. Small Scenario Factor Loadings Matrix for the Experimental Design.

| Factor | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| C-5A use rate | **0.845** | -0.025 | 0.395 | 0.080 |
| C-5A average payload | **0.730** | -0.538 | -0.063 | 0.146 |
| C-5A MTMs/aircraft/day | **0.885** | -0.127 | 0.330 | 0.107 |
| C-141B use rate | **-0.889** | -0.008 | -0.201 | 0.278 |
| C-141B g-cycle time | **0.757** | -0.179 | 0.060 | -0.058 |
| C-141B average payload | **-0.881** | 0.120 | -0.210 | 0.113 |
| C-141B MTMs/aircraft/d | **-0.914** | 0.014 | -0.224 | 0.260 |
| C-17 use rate | -0.216 | **0.841** | -0.141 | 0.385 |
| C-17 g-cycle time | **0.760** | -0.390 | -0.064 | -0.035 |
| C-17 average payload | 0.459 | **-0.801** | -0.082 | 0.188 |
| C-17 MTMs/aircraft/day | **0.631** | 0.271 | -0.234 | **0.590** |
| KC-10 use rate | **0.832** | -0.128 | 0.305 | 0.062 |
| KC-10 average payload | **-0.586** | 0.150 | -0.305 | -0.011 |
| KC-10 MTMs/aircraft/da | **0.767** | -0.136 | 0.292 | 0.121 |
| B-747P use rate | **0.841** | -0.126 | 0.347 | 0.115 |
| Outsize tons delivered | 0.041 | **0.930** | 0.237 | -0.106 |
| Passengers delivered | **0.749** | -0.135 | 0.395 | 0.209 |
| Total cargo tons deliv | -0.140 | -0.086 | 0.144 | **0.942** |
| % Shipments ontime | -0.350 | -0.290 | **-0.810** | -0.040 |
| Average days late | 0.432 | 0.066 | **0.783** | 0.008 |
| Eigenvalues | 9.4591 | 2.9796 | 2.3861 | 1.7092 |
| Common Variance (%) | 57.2% | 18.0% | 14.4% | 10.3% |

The eigenvalues and their corresponding percentages of the common variance are also listed in Table 4-7. Factor 1 was, by a large margin, the most significant of the

factors. It was interesting to note how the loadings on the four factors separated the throughput variables into three categories: outsize cargo, passengers, and total cargo. These three categories provided a logical basis for interpretation of the data:

***Factor 1. Widebody and Passenger Index.***

- ***Significance***: In general, high factor 1 scores reflect: high passenger throughput; high C-5, KC-10, and B-747P use/performance; and low C-141B use/performance.

- ***Insight***: Variance in C-5 and B-747P use rates accounted for most of the variance in passenger throughput. C-141 and C-17 ground cycle times understandably showed a corresponding increase when C-5 and B-747P aircraft were used more, due to competition for MOG resources. The KC-10, though not a passenger carrying aircraft, loaded highly on this factor also, primarily because its preference for bulk cargo complemented the cargo and passenger preferences of the C-5 and B-747P (see Table 2-2). The contrast between C-5 payload and both the C-141B and KC-10 payloads probably reflect competition for oversize cargo.

***Factor 2. Outsize Cargo Index.***

- ***Significance***: In general, high factor 2 scores reflect high outsize cargo throughput and high C-17 use with less efficient payloads.

- ***Insight***: Variations in outsize cargo throughput performance was accounted for by C-17 usage. The negative loading for C-5 payload reflected competition with the C-17 for outsize cargo. The negative loading for C-17 payload indicated less efficient use of C-17 payload capacity when carrying outsize cargo.

***Factor 3. Lateness Index.***

- ***Significance***: In general, high factor 3 scores reflect more late deliveries.

- ***Insight***: Once again, the timeliness performance measures are distinctly independent of the other performance measures.

***Factor 4. Total Cargo Index.***

- ***Significance***: In general, high factor 3 scores reflect high total cargo throughput and high C-17 MTM/D throughput.

- ***Insight***: Variations in total cargo throughput performance was accounted for by variations in C-17 MTM/D throughput performance. Since factor 2 accounted for the outsize cargo, this factor probably reflects the variation in the remaining cargo, including only oversize and bulk cargoes.

Combined, factors 2 and 4 reflect the small scenario's preference for the C-17 aircraft's small MOG requirement and its versatility with all types of cargo. This was expected, because the limited MOG available among the seven primary APOD's makes this scenario sensitive to the smaller aircraft types.

The sensitivity of the small scenario to the various perturbations is graphically depicted in Figures 4-4, 4-5, and 4-6. These "sensitivity" plots were created by SAS and show factor 1 scores plotted against factors 2, 3, and 4 scores, respectively. Each plotted symbol reflects the design point identification code for one run (see Table 3-1).

When interpreting the sensitivity plots, use the cluster of 0's as a reference point. The size of the cluster of 0's represents, in a graphical way, the AFM internal noise, or variance that was expected from changing the random seed. For this analysis, this internal random noise was assumed to be fairly constant throughout the experimental design space. Design points (such as 4, 5, 6, 7, and 9) with a cluster larger in size than the cluster of 0's represent an increase in *performance variance* due to the perturbation effects. Relative increases or decreases in mean airlift system performance are reflected in the lateral displacements of the clusters from each other. These lateral displacements reflect a change in the scenario's mean performance due to the perturbations. The following discussions of the effects of perturbations refers to the magnitude of these lateral displacement as the amount of *performance mean sensitivity* to the perturbations.

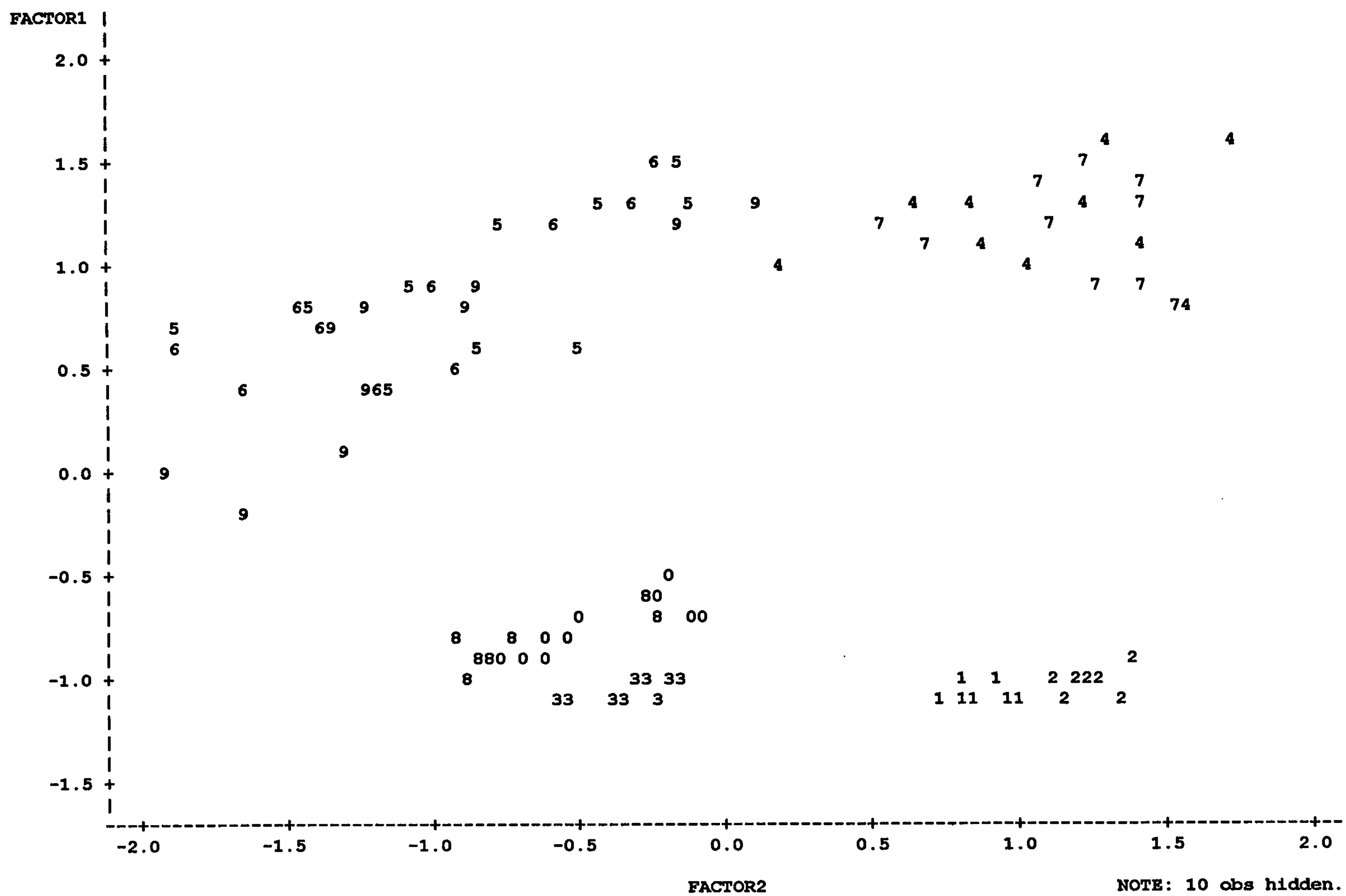


Figure 4-4. Sensitivity Plot of Widebody and Passenger Index vs. Outsize Cargo Index (Small Scenario)

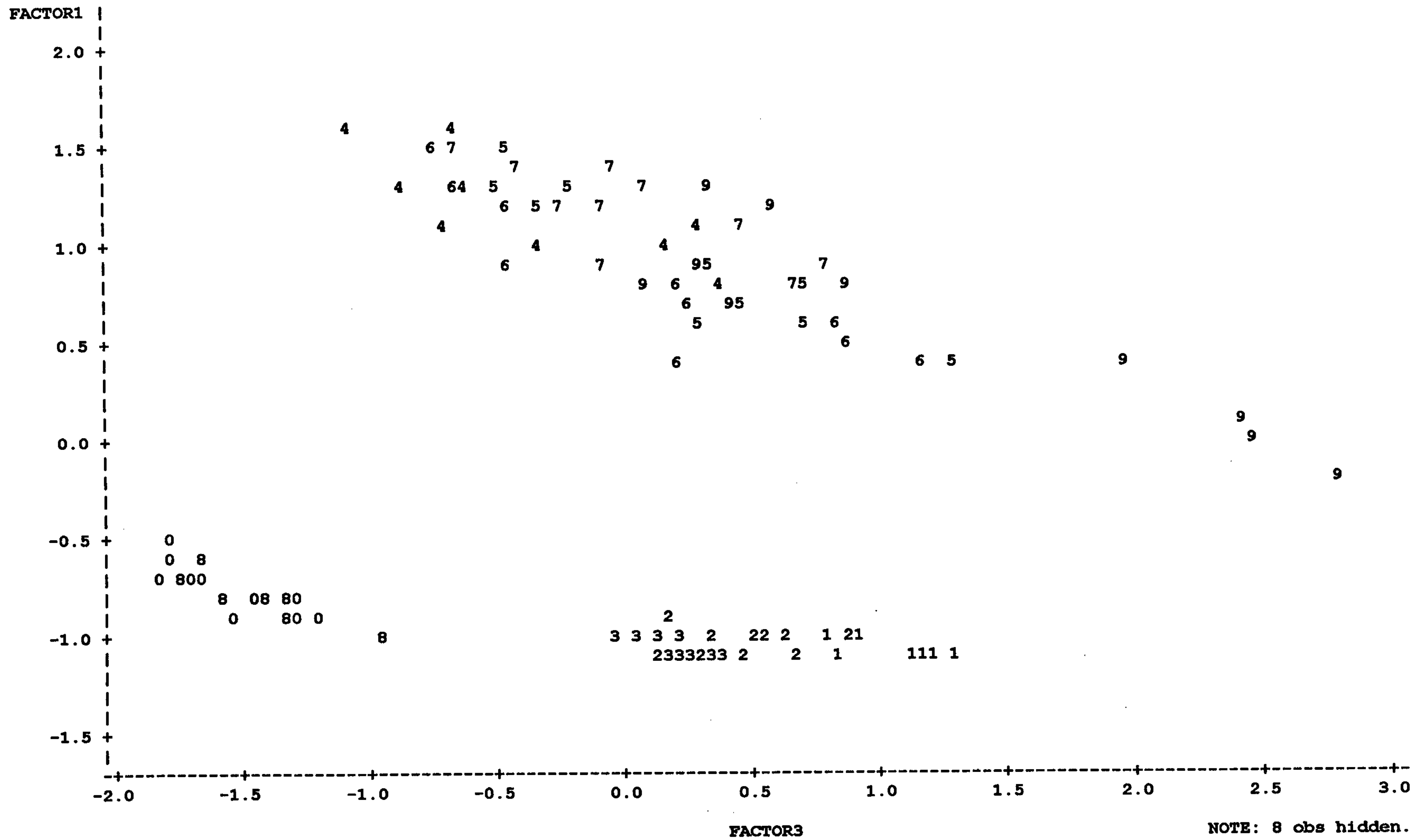


Figure 4-5. Sensitivity Plot of Widebody and Passenger Index vs. Lateness Index (Small Scenario)

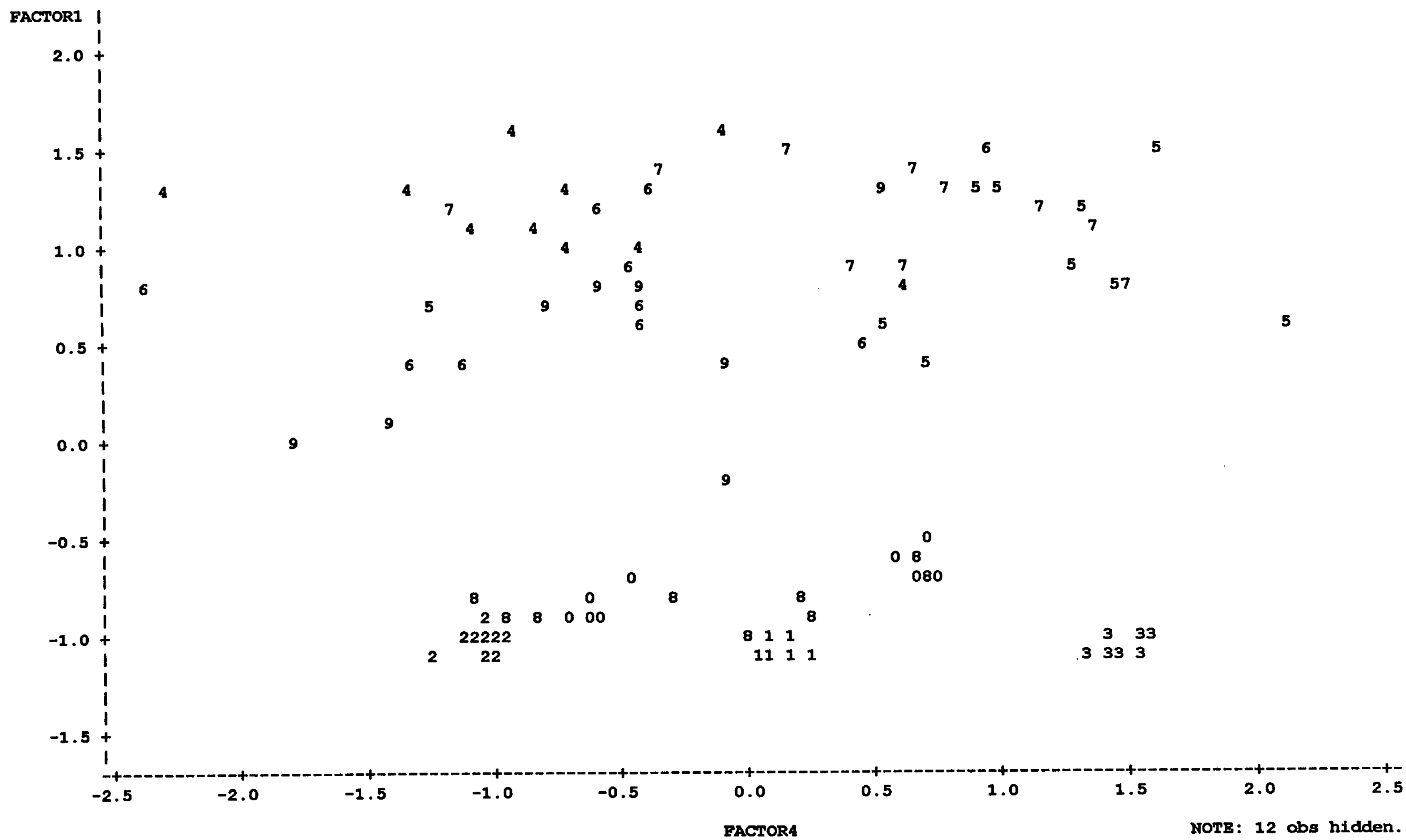


Figure 4-6. Sensitivity Plot of Widebody and Passenger Index vs. Total Cargo Index (Small Scenario)

The *performance variation*, as measured by all four performance indices, significantly increased with the APOE/APOD perturbations (design points 4, 5, 6, 7, and 9). The *performance mean sensitivity* to APOE/APOD perturbations was fairly significant for the Passenger Throughput Index, but not significant for the other indices. Figure 4-4 seems to indicate a possible interaction or tradeoff between passenger throughput and lateness, as seen by the diagonal alignment of the 4, 5, 6, 7, and 9 design points. This interaction between passengers and lateness was also noted as a characteristic of this scenario during the analysis of the random seed runs (See the discussion of Factor 4 from Table 4-6). Though the APOE/APOD perturbation scheme was very simplistic, Figures 4-4 and 4-6 imply that *it is possible to improve passenger throughput for this scenario, without sacrificing cargo throughput*, by using different onload and offload locations.

The *performance variation* and *performance mean sensitivity* to ALD/RDD perturbations (design points 2, 3, 6, 7, and 8) were not significant for any of the indices. The implication was that *passenger and cargo throughput, in terms of numbers of people and cargo tonnage, remained fairly constant*, despite changes to the order of the requirement lines in the TPFDD and changes of no more than one day to the ALD and RDD timeline. Another implication was that *aggregate measures of timeliness (or lateness), also remained fairly constant*. The two timeliness performance variables are considered aggregate measures of timeliness in that they reflect the timeliness of all delivered shipments.

The *performance variation* due to the 10 percent load strain perturbations (design points 1, 3, 5, and 7) was not significant for any of the indices. The *performance mean*

*sensitivity* to load strain perturbations was mildly significant only for the Total Cargo Throughput Index and possibly the Outsize Cargo Throughput Index. In Figure 4-6, the lack of a significant vertical displacement between the cluster of 0's and the clusters of 1's and 3's indicates that the load strain perturbations, which increased passenger requirements 10%, have little impact on the Passenger Throughput Index. Figure 4-6 shows most of the 1, 3, 5, and 7 plots on the right side of the plot, possibly indicating a mild increase in total cargo throughput. Whether or not this increase is statistically significant, *this scenario cannot handle much of an increase in demand for passenger or cargo traffic*. The *performance mean sensitivity* of outsize cargo throughput, as seen by the horizontal displacements in Figure 4-4, appear insignificant except for the slight negative horizontal displacement between the clusters of 1's and 2's. The only notable difference between design points 1 and 2 is the change in the proportions of outsize and oversize cargo (ALD/RDD effects were insignificant). Outsize cargo throughput seemed indifferent to the load strain perturbation until the relative proportions between the cargo classes changed, implying that *the relative proportions between the cargo classes can impact the significance of effects caused by straining the system.*

The *performance variation* due to perturbing the relative proportions of outsize and oversize cargo (design points 1, 2, 4, and 7) was not significant. However, the *performance mean sensitivity* to perturbing the relative proportions of outsize and oversize cargo was mildly significant for the Lateness Index and very significant for the Outsize Throughput Index. Figure 4-5 shows a small relative increase in lateness performance. Figure 4-4 shows a large relative increase in outsize cargo throughput

performance. Since C-17 use rate also loads fairly high on factor 2, the increase in outsize cargo throughput is most likely due to the C-17's capability to deliver outsize cargo into small airfields. *Though there was an increase in outsize cargo performance, there was no discernible change in total cargo throughput performance*, as shown in Figure 4-6, indicating the consistency of the total cargo throughput measure.

It is interesting to note, across all four perturbation schemes, how the total cargo throughput index was relatively unaffected, reflecting the consistency and robustness of the *total cargo tons delivered* variable. The robustness of this variable was also indicated in the analysis of the large scenario.

Large Scenario. Appendix F contains the raw AFM output data for the 100 runs used during this portion of the research. Using the SAS procedure, PROC FACTOR with a VARIMAX rotation, on this set of 100 runs resulted in the factor loadings matrix presented in Table 4-8. AFM did not reliably output C-17 ground cycle statistics for all design points, so the variable was discarded, leaving 30 variables for factor analysis.

The eigenvalues and their corresponding percentages of the common variance are also listed in Table 4-8. Factor 1 was, by a large margin, the most significant of the eight factors. It was interesting to note how the three throughput categories, outsize cargo, passengers, and total cargo, separated again onto three different factors.

Table 4-8. Large Scenario Factor Loadings Matrix for the Experimental Design

| Factor | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| C-5A use rate | **0.588** | -0.030 | -0.249 | 0.353 | 0.065 | -0.148 | 0.213 | 0.060 |
| C-5A g-cycle time | **-0.826** | 0.226 | -0.005 | -0.251 | 0.003 | 0.099 | 0.040 | -0.085 |
| C-5A average payload | -0.136 | **0.512** | 0.164 | -0.040 | -0.296 | 0.140 | 0.182 | **0.490** |
| C-5A MTMs/aircraft/day | 0.219 | 0.200 | 0.301 | **0.702** | 0.043 | -0.001 | 0.100 | 0.306 |
| C-141B use rate | -0.279 | -0.057 | -0.017 | **0.763** | 0.092 | 0.203 | -0.182 | -0.160 |
| C-141B g-cycle time | -0.223 | 0.090 | -0.054 | **-0.692** | 0.032 | -0.233 | 0.298 | 0.329 |
| C-141B average payload | -0.401 | 0.246 | 0.298 | 0.197 | -0.129 | 0.198 | 0.030 | **-0.616** |
| C-17 use rate | **0.714** | 0.112 | -0.124 | -0.415 | 0.335 | -0.010 | -0.173 | 0.005 |
| C-17 average payload | -0.093 | **0.902** | 0.133 | -0.096 | 0.068 | -0.027 | -0.103 | -0.012 |
| C-17 MTMs/aircraft/day | 0.065 | **0.744** | 0.001 | -0.090 | 0.334 | 0.007 | -0.342 | -0.249 |
| KC-10 use rate | **0.730** | 0.113 | 0.083 | -0.415 | 0.252 | 0.007 | -0.189 | -0.073 |
| KC-10 g-cycle time | **-0.876** | 0.034 | 0.031 | 0.267 | -0.049 | 0.003 | 0.241 | -0.077 |
| KC-10 average payload | -0.130 | 0.033 | **0.857** | 0.213 | -0.091 | -0.138 | -0.101 | 0.110 |
| KC-10 MTMs/aircraft/day | 0.317 | 0.026 | **0.847** | 0.055 | 0.048 | -0.165 | -0.134 | -0.057 |
| B-747 use rate | **0.809** | 0.090 | 0.154 | -0.054 | 0.314 | -0.007 | 0.061 | 0.074 |
| B-747 g-cycle time | 0.187 | -0.006 | 0.155 | -0.006 | 0.173 | -0.240 | -0.090 | **0.761** |
| B-747 average payload | -0.210 | 0.031 | **-0.517** | 0.046 | -0.082 | 0.065 | **0.628** | 0.062 |
| B-747 MTMs/aircraft/day | **0.905** | -0.036 | 0.099 | 0.082 | 0.282 | -0.045 | 0.071 | 0.051 |
| B-747P use rate | **0.681** | -0.090 | -0.048 | -0.023 | 0.234 | -0.232 | 0.220 | 0.131 |
| B-747P g-cycle time | 0.468 | 0.026 | 0.247 | -0.021 | **0.611** | -0.090 | 0.108 | 0.151 |
| DC-8 use rate | -0.177 | 0.029 | -0.063 | 0.050 | 0.006 | **0.893** | 0.100 | -0.179 |
| DC-8 g-cycle time | -0.002 | 0.048 | 0.200 | -0.241 | 0.251 | **-0.835** | 0.102 | 0.077 |
| DC-8 average payload | 0.190 | -0.094 | -0.165 | -0.222 | -0.045 | -0.008 | **0.778** | -0.089 |
| DC-8 MTMs/aircraft/day | **0.919** | -0.038 | 0.118 | -0.034 | 0.220 | -0.016 | 0.126 | 0.089 |
| Outsize tons delivered | -0.090 | **-0.777** | 0.023 | -0.186 | 0.236 | 0.032 | -0.160 | -0.060 |
| Passengers delivered | 0.047 | -0.288 | **-0.577** | 0.158 | -0.409 | -0.094 | 0.165 | -0.103 |
| Total cargo tons delivered | **0.874** | 0.170 | 0.112 | 0.338 | -0.117 | 0.007 | -0.018 | 0.021 |
| % Shipments ontime | -0.500 | 0.189 | -0.006 | -0.041 | **-0.744** | 0.120 | 0.064 | -0.071 |
| Average days late | 0.439 | 0.037 | -0.060 | 0.104 | **0.716** | -0.161 | -0.127 | 0.046 |
| Eigenvalues | 7.689 | 2.607 | 2.586 | 2.574 | 2.484 | 1.903 | 1.679 | 1.654 |
| Common Variance (%) | 33.2% | 11.3% | 11.2% | 11.1% | 10.7% | 8.2% | 7.2% | 7.1% |

***Factor 1. Total Cargo Index.***

- ***Significance***: In general, high factor 1 scores reflect high cargo throughput and high aircraft performance.

- ***Insight***: Except for the C-141B and the DC-8, all aircraft use rates were positively correlated with cargo throughput. Though not contributing to total cargo throughput, B-747P (passenger version) aircraft also loaded highly upon this first factor, providing part of the passenger dimension to this factor as well. The

exclusion of the smaller C-141B and DC-8 aircraft from this first factor reflects the scenario's preference for the larger, longer range aircraft.

***Factor 2. C-17 and Outsize Cargo Contrast.***

- ***Significance***: In general, high factor 2 scores reflect high C-17 throughput performance and low outsize cargo throughput. Low factor 2 scores reflect more outsize cargo throughput, but less efficient use of C-17 payload capacity.

- ***Insight***: In contrast to the small scenario, where C-17 throughput and Outsize throughput were positively correlated, this scenario shows a negative correlation between these variables. The long distance between APOE/APOD pairs in this scenario most likely forced a tradeoff between C-17 payload and fuel. Less fuel and more payload meant stopping more often for fuel, which slowed the rate of C-17 deliveries, decreasing overall C-17 throughput. Therefore, increasing C-17 MTM/D throughput resulted from taking on more fuel and less outsize payload. Since the C-5 payload is positively correlated with C-17 throughput measures, the same argument applies to C-5 payload and fuel tradeoffs. These two aircraft types deliver most of the outsize cargo in this scenario, and the flow of outsize cargo seems to benefit from their sacrificing a little payload for extra fuel to fly further.

***Factor 3. KC-10 and Passenger Contrast.***

- ***Significance***: In general, high factor 3 scores indicate high KC-10 throughput performance and low passenger throughput performance.

- ***Insight***: This factor also reflects competition between KC-10 and B-747 aircraft for cargo, which is understandable because they share an almost exclusive preference for bulk cargo. Since KC-10 and B-747 aircraft were not able to carry passengers, the *passengers delivered* variable seemed misplaced. There might be a MOG resource constraint reflected in this relationship, where larger payloads on KC-10 aircraft caused KC-10 aircraft to spend more time on the ground and limited the amount of MOG resources left for passenger carrying aircraft. Including the B-747P use rate observations in Factor 1, passenger throughput performance does not seem to be as clearly separated from the many dimensions of cargo throughput performance, which contrasts with their distinct independence in the small scenario.

***Factor 4. C-5 MTM/D and C-141B Use Rate Index.***

- ***Significance***: A high factor 4 score reflects high C-141B use and high C-5 MTM/D throughput performance.

- ***Insight***: There was a positive correlation between C-141B use rate and C-5 MTM/D throughput performance in this scenario. Factor 8 will complete the

second dimension of the C-5 and C-141B relationship in this scenario. Though competition for common payloads (oversize and bulk cargo) is evident in the Factor 8 loadings, this factor also possibly reflects a different dimension of oversize and bulk cargo throughput.

***Factor 5. Lateness Index.***

- ***Significance***: In general, a high factor 5 score reflects more late deliveries.

- ***Insight***: As was seen in the random seed runs, CRAF aircraft again were identified with timeliness performance, indicating the importance of CRAF aircraft to successful timeliness performance.

***Factor 6. DC-8 Use Rate Index.***

- ***Significance***: In general, a high factor 6 score reflects high DC-8 use and low DC-8 ground times.

- ***Insight***: This factor directly reflects the amount of flying performed by the DC-8 fleet in this scenario.

***Factor 7. CRAF Payload Index.***

- ***Significance***: In general, a high factor 7 score reflects high DC-8 and B-747 payloads, which together add up to total CRAF cargo payload capacity.

- ***Insight***: This factor indicates a positive correlation between DC-8 and B-747 cargo payloads. Though these two aircraft share a preference for bulk cargo, there was no apparent competition for payloads between them. Instead of competing with each other, Factor 8 loadings indicate that B-747 aircraft may be competing with the military cargo aircraft. This observation combined with the relationship between B-747 and DC-8 payloads found in this factor indicate a competition for cargo between CRAF and military aircraft. The reason this relationship was spread over the last two factors in independent CRAF and military dimensions most likely has to do with the fact that the military and civilian aircraft "fly" different airways and use a different airlift system network structure in AFM.

***Factor 8. C-5 and C-141B Payload Contrast.***

- ***Significance***: In general, a high factor 8 score reflects high C-5 payloads, low C-141B payload, and longer B-747 ground times. Low factor 8 scores reflect low C-5 payloads, high C-141B payloads, and shorter B-747 ground times.

- ***Insight***: Competition between C-5 and C-141B payloads indicated here complete the relationship found between these two aircraft types in Factor 4. The

significant loading of B-747 ground times relates to either MOG constraints or competition for cargo, as previously mentioned in the Factor 7 insights.

The sensitivity of the large scenario to the various perturbations can be seen by looking at the sensitivity plots, Figures 4-7 and 4-8. As before, each plotted symbol reflects the design point identification code for one run (see Table 3-1). There are many possible combinations of the 8 factors that could be used to provide other sensitivity plots, but only two were needed to support the following discussion. Appendix F contains the factor scores for each run and can be plotted to obtain more sensitivity plots, if desired.

When interpreting the sensitivity plots, use the cluster of 0's as a reference point. For this analysis, internal random noise was assumed to be constant throughout the experimental design space. The size of the cluster of 0's represents, in a graphical way, the AFM internal noise, or variance that was expected from changing the random seed. Design points (such as 4, 5, 6, 7, and 9) with a cluster larger in size than the cluster of 0's represent an increase in *performance variance* due to the perturbation effects. Relative increases or decreases in mean airlift system performance is reflected in the lateral displacement of the clusters from each other. The relative displacements of the clusters reflect the *performance mean sensitivity* to the perturbations.

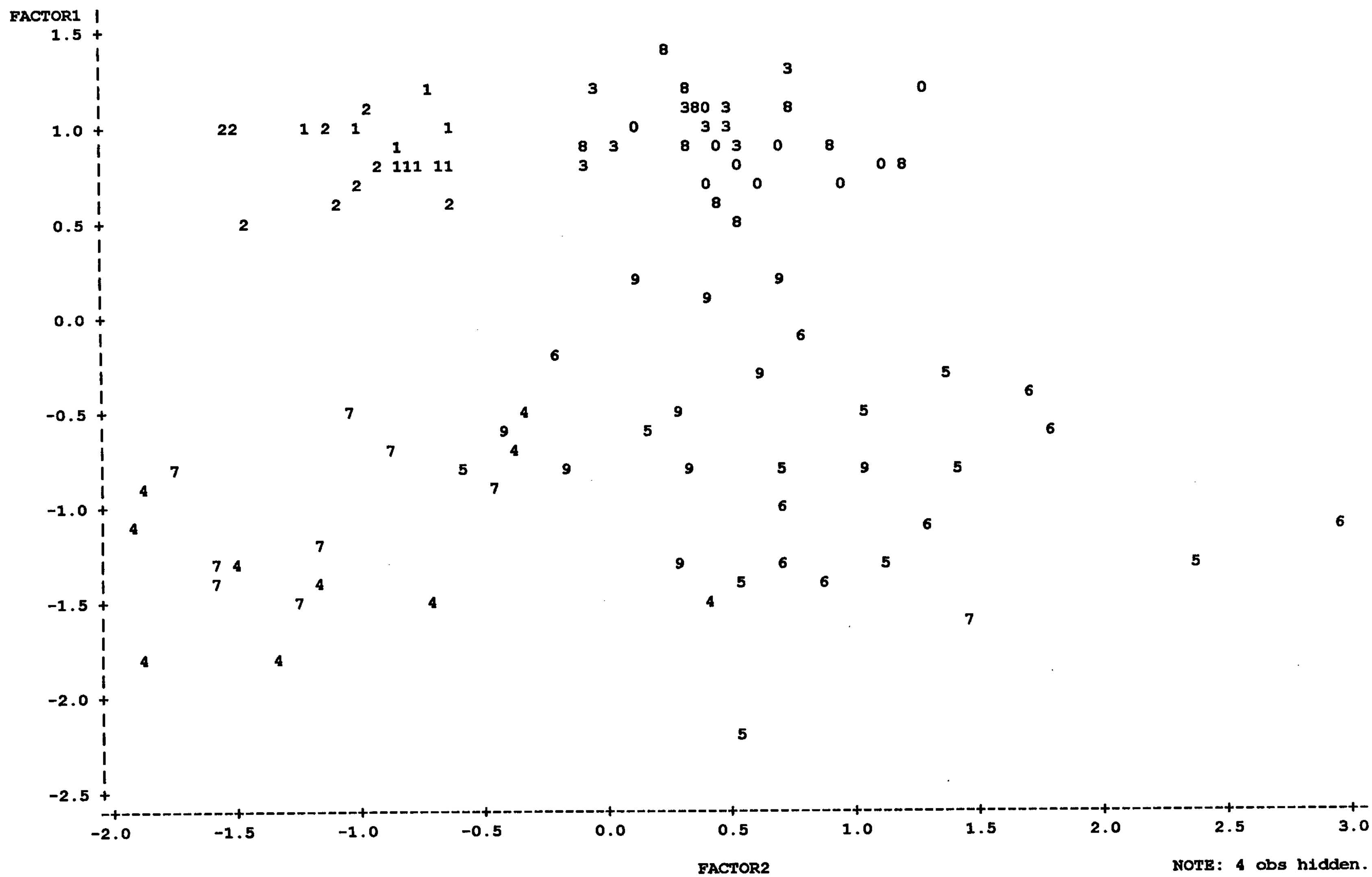


Figure 4-7. Sensitivity Plot of Total Cargo Index vs. C-17 and Outsize Cargo Contrast (Large Scenario)

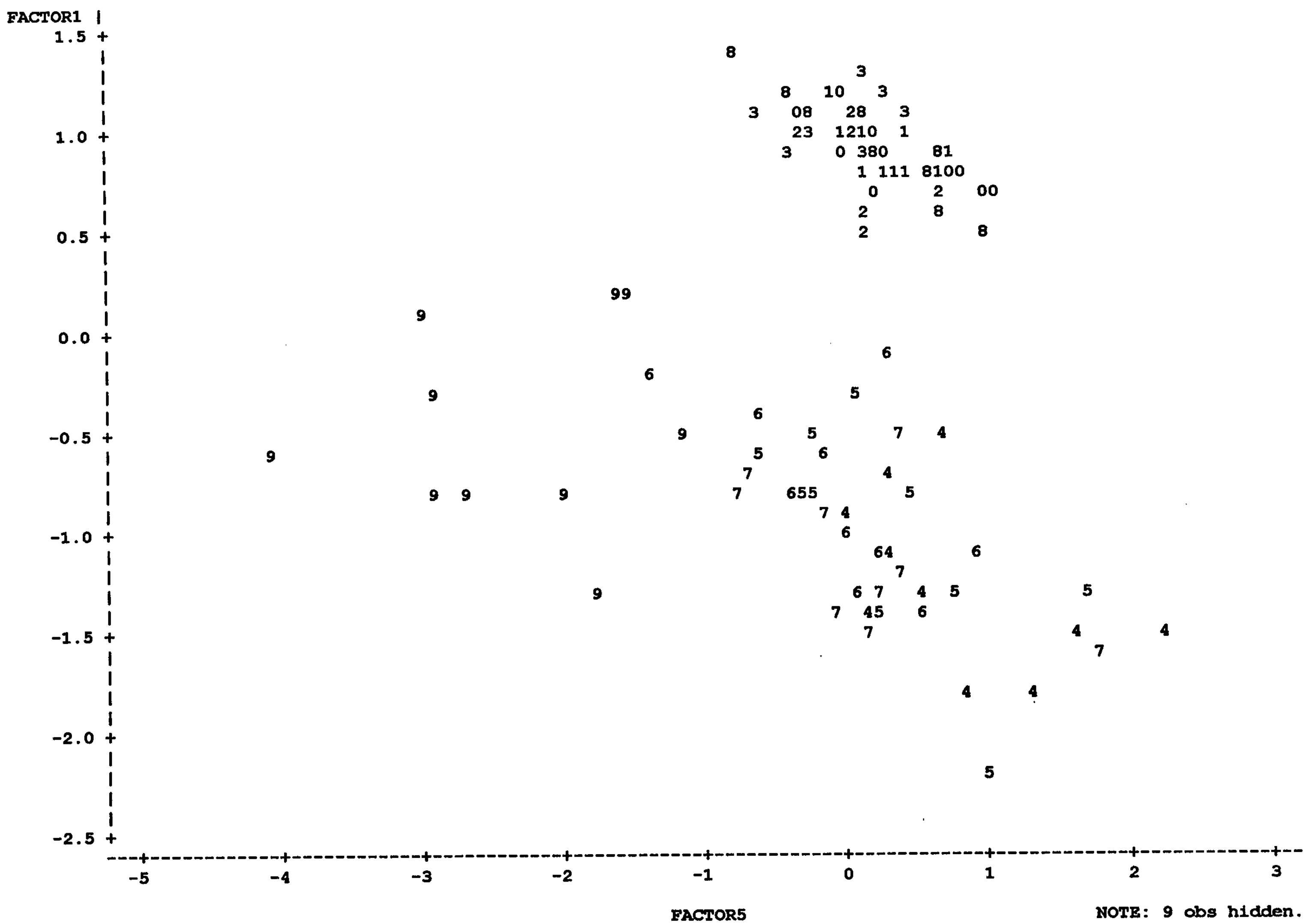


Figure 4-8. Sensitivity Plot of Total Cargo Index vs. Lateness Index (Large Scenario)

The *performance variation*, as measured by all eight performance indices, significantly increased with the APOE/APOD perturbations (design points 4, 5, 6, 7, and 9). The *performance sensitivity* to APOE/APOD perturbations was significant for the Total Cargo Throughput Index, but not significant for the other indices. The negative vertical displacement of these design points relative to the other design points in Figure 4-7 implies that *randomly changing APOE/APOD pairs decreased total cargo throughput performance and/or aircraft use rates.* However, looking at the cluster of 9's versus the cluster of 0's in Figure 4-8 reveals a positive impact on timeliness.

The *performance variation* and *performance sensitivity* to ALD/RDD perturbations (design points 2, 3, 6, 7, and 8) were not significant for any of the indices. The implication was that *airlift system performance, by all measures, remained fairly constant*, despite changes to the order of the requirement lines in the TPFDD and changes of no more than one day to the ALD and RDD timeline.

The *performance variation* and *performance sensitivity* due to the 10 percent load strain perturbations (design points 1, 3, 5, and 7) were not significant for any of the indices. The obvious implication from this result was that *this scenario was tasking the airlift system to capacity and it could not handle any increase in demand for passenger or cargo traffic.*

The *performance variation* due to perturbing the relative proportions of outsize and oversize cargo (design points 1, 2, 4, and 7) was not significant. However, the *performance sensitivity* to perturbing the relative proportions of outsize and oversize cargo was mildly significant for the C-17 and Outsize Cargo Contrast (See Figure 4-7).

Figure 4-7 shows the small negative displacement of the 1's and 2's relative to the 0's and 3's, indicating a slight increase in outsize throughput performance. *Though there was a slight increase in outsize cargo throughput performance, there was no discernible change in total cargo throughput performance*, as shown in the vertical dimension of Figure 4-7, indicating the consistency of the total cargo throughput measure once again.

Summary of Perturbation Runs. The application of factor analysis as a sensitivity analysis tool was demonstrated and seemed useful in identifying the effects of the four perturbation schemes used. The sensitivity plots graphically depicted the effects of the combination of perturbations included in each experimental design point. These sensitivity plots indicated that airlift system performance, as measured by AFM output, was affected by perturbations to the TPFDD. In the small scenario, the perturbation schemes seemed to have a greater effect than in the large scenario, where the airlift system was tasked to capacity.

In both scenarios, total cargo throughput seemed to be robust and consistent, relatively unaffected across all perturbation schemes. This is particularly noteworthy, because it puts in perspective the frequent historical use of *total tons delivered* as an indicator of overall airlift system performance. For measuring overall cargo throughput, there can obviously be many variations of the TPFDD and this statistic would still be a reasonable measure of how many tons could be delivered. However, to use this variable as the sole measure of airlift system performance would ignore pertinent information on the many other aspects of airlift performance.

Perturbing APOE/APOD pairs significantly affected variance of most performance measures. Though the coded algorithm may not have been a very realistic approach to changing APOE/APOD pairs, the results from blindly changing APOE/APOD pairs had significant consequences for some major indices of airlift system performance. In the small scenario, passenger throughput significantly increased, as expected, by redistributing the passengers amongst the destination airports. For the same reasons passenger throughput was expected to increase in the small scenario, cargo throughput was expected to increase in the large scenario. However, cargo throughput significantly decreased as a result of this perturbation scheme. The unpredictability and high sensitivity of airlift system performance to this perturbation scheme seemed almost chaotic, where relatively small changes to input caused large changes in output (Bauer, 1996). This high sensitivity to APOE/APOD changes could have also been a result of too large a perturbation. Allowing a maximum of a ten percent change in distance between APOE and APOD for each line of a TPFDD could have been too much. It is possible that smaller perturbations might have had a more stable and predictable effect on AFM output. Whether the result is due to chaos or too large a perturbation, AFM output subject to completely *unconstrained* random TPFDD generation, with respect to the APOEs and APODs, would most likely be as sensitive and unpredictable and is not recommended.

Perturbing available-to-load dates (ALD's) and required delivery dates (RDD's), by plus or minus one day, and re-sorting the TPFDD by RDD then ALD, impacted the order in which the requirements were processed by AFM. Though the requirements were processed in a different order and the timeline was slightly disturbed, AFM output was

relatively unaffected by this perturbation scheme. The major implication to be highlighted from this result is that the relative order and priority of the individual TPFDD requirement lines have no significant impact on aircraft usage or total system throughput measures. Other aspects of airlift system performance, like combat unit closure, might be affected, but were not considered during this research.

Increasing all cargo and passenger requirements by 10% to strain the airlift system, effected increased performance in the small scenario, where the airlift system had more unused capacity; but it had little impact on the large scenario. Knowing that most TPFDDs start out transportationally impossible and that cargo and passenger delivery timelines for most TPFDDs are relaxed until they are transportationally feasible, this perturbation seemed more of a curiosity than a useful endeavor. However, this perturbation was useful in identifying what areas of airlift performance had unused capacity still available and what areas didn't.

As mentioned in Chapter II, possible changes to national pre-positioning strategy would cause a shift in the amounts of outsize and oversize cargoes within the TPFDD requirements. Perturbing the TPFDDs to reflect this change, in favor of increasing outsize at the expense of oversize cargo, did not seem to affect total cargo tons delivered in either scenario. In general, an increase in outsize cargo delivered was noted, but not always. In the small scenario, when combining this perturbation with the load strain perturbation, outsize cargo delivered was less than with the load strain perturbation alone.

## Summary

In light of the problem statement and research objectives mentioned in Chapter I, the following general methodology for conducting airlift system performance analysis with perturbed TPFDDs was demonstrated:

1) Identify AFM output variables reflecting desired MOE's
2) Analyze sensitivities to AFM random seed using factor analysis
3) Define perturbation schemes
4) Analyze sensitivities to perturbations using factor analysis

These general steps were used to identify the relative effects of four TPFDD perturbation schemes on AFM output variables, indicating that airlift system performance was affected.

In addition to demonstrating the above methodology, the results from the random seed run data provide the first known documentation on the effects of changing the AFM simulation's initial random seed. A promising application of factor analysis to large, stochastic simulation model verification and validation was also demonstrated. A potential quirk in the trivial load portion of the mission scheduling heuristic was identified during this portion of the analysis.

During analysis of the perturbation run data, sensitivity plots provided a nice graphical tool for conducting sensitivity analysis for complex stochastic processes. The sensitivity plots were a result of plotting the resulting factor scores for each run on separate axes. The plotted points were coded point with a symbol reflecting the specific perturbation schemes tested. The effects of the perturbations on mean performance and on the associated variance of that performance were easly identified from the sensitivity plots.

# V. Conclusions and Recommendations

## Introduction

This chapter provides a summary of conclusions and recommendations resulting from this thesis effort. At the end of the chapter, some suggestions for possible future research are also provided.

## Conclusions

This thesis was an exploratory look into the effects of a varying TPFDD on airlift system performance. The 3-step general methodology, as outlined and demonstrated in this thesis, provided an approach to analyzing airlift system performance across several similar TPFDDs by perturbing a given TPFDD. In general, airlift system performance was affected, and sometimes significantly, by the perturbation schemes used. The high degree of sensitivity with respect to the locations specified in the TPFDD seemed to counter arguments supporting the usefulness of unconstrained random TPFDD generation in airlift analysis.

*Total cargo tons delivered* was fairly insensitive to all perturbation schemes, indicating the robustness and consistency of this airlift system performance measure. This observation points out the strength and weakness of this measure as the sole indicator of airlift system performance. The strength lies in the fact that there could be many variations of a TPFDD, or errors in a TPFDD, and this measure would reflect the total throughput capacity of the airlift system. The weakness lies in the lack of information on

the many other aspects of airlift system performance. In particular, timeliness of deliveries, another key aspect of airlift system performance, is not at all reflected or implied by the total cargo throughput measure. So, as a measure of raw airlift system capacity, total cargo tons delivered seems to be a fairly useful and robust statistic, being fairly insensitive to many details within the TPFDD. But as a measure of how well the airlift system performed, as a whole, this statistic lacks the information required to make such an assessment.

This thesis also provides the first known documentation on the effects of the AFM simulation's initial random seed on AFM output. Most of the output variables collected for this research had a coefficient of variation less than 3 percent.

Factor analysis, as applied in this research, was useful in determining sensitivities to the perturbations and in keeping the size of the problem manageable. During analysis of the random seed run data, the potential for a new application of factor analysis to stochastic simulation model verification and validation was demonstrated. During analysis of the perturbation run data, the potential for another new application of factor analysis to sensitivity analysis of complex stochastic processes was demonstrated. In particular, the sensitivity plots, when coded by the experimental design point identification codes, provided an extremely useful graphical tool for conducting sensitivity analysis.

<u>Recommendations</u>

The AFM mission scheduling heuristic seemed to be incompatible with the large number of detailed cargo requirements in the small scenario's TPFDD. Many of these detailed requirements were considered trivial loads by most of the modeled aircraft types.

The AFM simulation's heuristic to indirectly collect those trivial loads instead of dispatching an aircraft to collect them seemed extremely sensitive to the frequency with which the various types were scheduled. Though the effects of this quirk in the mission scheduling heuristic were relatively small on the practical level, a more stable heuristic should be investigated to improve the fidelity of the AFM simulation.

Due to the high degree of sensitivity observed in airlift performance, with respect to the locations specified in the TPFDD, *unconstrained* random TPFDD generation is not recommended.

A perturbed TPFDD approach to airlift system analysis could provide useful information during the TPFDD creation process, identifying which characteristics of the TPFDD are hindering airlift system performance.

Suggestions for Future Research

There were many aspects of airlift system performance that could be evaluated in this research. The potential exists to investigate the effects of TPFDD perturbations on more focused, detailed performance variables (e.g. crew performance statistics, individual unit closure, etc.). The four perturbation schemes used in this research are not the only ways to perturb TPFDD data. Therefore, another opportunity exists for repeating this research with a different set of perturbation schemes.

The methodology presented in this thesis also applies to changes, or perturbations, in other inputs to the airlift system as well. Effects of varying MOG resources, MHE resources, or fleet mixes could be analyzed in the same manner.

There seems to be a fairly strong push to randomly generate TPFDDs for use in airlift analysis (Hagin, 1996). This capability would allow for analysis in situations where a formal TPFDD is not available. For instance, in Operation Desert Shield we began the deployment phase without an operational plan or a feasible transportation plan (Lund and others, 1993:xiv). Without a TPFDD, pre-deployment analysis was limited and the resulting policy decisions were not as effective as they could have been. The result, as documented by RAND, was inefficient performance of the airlift fleet during the first weeks of the operation (Lund and others, 1993:xiv). For this type of situation in the future, randomly generated TPFDDs could provide a basis for airlift performance analysis. Based on the results of this research, aside from the aspect of operational feasibility for any randomly generated TPFDD, well-defined constraints on certain characteristics of a TPFDD will be needed to keep performance measures stable enough to be useful.

## Appendix A: Description of Airlift Flow Module Input File 63

The following file description was extracted from the documentation provided with the Airlift Flow Module (AFM) software.

### Input File 63, Requirement Description

USE: The MASS cargo requirement as derived from a TPFDD.

| ITEM | LENGTH | FORMAT | COLUMNS | REMARKS |
|---|---|---|---|---|
| requirement_id | 5 | i5 | 1 - 5 | Unique ID (1)(2) |
| theater | 10 | a10 | 6 - 15 | (3) |
| jopes_priority | 5 | i5 | 16 - 20 | Not used, Must be blank or 0 |
| commodity_code | 2 | i2 | 21 - 22 | See commodity code in file 50 |
| available_load_date | 3 | i3 | 23 - 25 | Day cargo available to load (4) |
| required_delivery_date | 3 | i3 | 26 - 28 | Day this cargo must be delivered (4) |
| APOE | 4 | a4 | 29 - 32 | Onload ICAO (7) |
| APOD | 4 | a4 | 33 - 36 | Offload ICAO (7) |
| direct_delivery_loc | 4 | a4 | 37 - 40 | Direct Delivery Location ICAO (7) |
| cargo_type | 1 | a1 | 42 - 42 | S - strategic or T - tactical |
| amount_1 | 7 | f7.1 | 44 - 50 | Outsize tons (5) |
| amount_2 | 7 | f7.1 | 51 - 57 | Oversize tons |
| amount_3 | 7 | f7.1 | 58 - 64 | Bulk tons |
| amount_4 | 7 | f7.1 | 65 - 71 | Number of pax (6) |

NOTES:
1. Must be grouped together by theater.
2. Do not exceed the maximum number of requirements allowed. Requirement_id can exceed the max number of requirements allowed.
3. The theater in file 31 and file 63 must match. Also, all file 31 theaters must have at least one file 63 requirement.
4. When processing a requirement, sort by available_to_load date, and then on the required_delivery_date so that the most demanding time windows are at the top of the file because AFM always processes FIFO. Then renumber the requirement ids in sequence, honoring like theaters. Hours 0-24 is Day 0, ... for ALD and RDD purposes.
5. For any given requirement, preferred cargo > 0, total compatible cargo must exceed an aircraft's trivial load limit, and the aircraft must be allowed to on/off at the APOE/APOD or the requirement will close (see File81) for that aircraft type.
6. The load amount for passengers is figured as tons using the formula: (amount_4 * 350.0) / 2000.0
7. All ICAOs used in file 63 must be in file 25, "Airbase List" and its supporting files.

## Appendix B: Small Scenario Random Seed Run Data

The 20 variables used in the analysis of the small scenario random seed runs are presented in this appendix. Each row of data represents the output from one run of AFM with the indicated random stream and the original small scenario file 63. At the bottom of each column of data are the mean, standard deviation, and coefficient of variation for the respective variables. The coefficient of variation is a statistical tool computed by dividing the standard deviation by the mean. In this case, the coefficients of variation are expressed as a percentage of the respective mean values. The relative magnitude of variation caused by changing the AFM initial random seed value, across all variables, can be understood by looking at the coefficients of variation.

The five factor scores listed in this appendix were computed using the SAS factor analysis procedure, PROC FACTOR, with a varimax rotation. The number of factors selected by the SAS, for this set of 20 variables, was 6. SAS uses the Kaiser criterion (the number of eigenvalues greater than or equal to 1) to determine the number of factors to retain. This default criterion was overridden with a manual command to retain only 5 factors because the 6-factor results were unsatisfactory. Two of the six factors had only 1 significant loading each. The eigenvalues for these two factors were fairly low (less than 1.23) compared to the other 4 factors. Retaining one less factor provided a more interpretable factor loadings matrix with more significant eigenvalues on all 5 factors.

| | C-5A | | | C-141B | | | | C-17 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Random Stream | Use Rate | Average Payload | MTM/D | Use Rate | G-Cycle Time | Average Payload | MTM/D | Use Rate | G-Cycle Time | Average Payload | MTM/D |
| 1 | 2.4 | 70.10 | 0.0180 | 8.1 | 11.39 | 27.50 | 0.0365 | 10.5 | 14.46 | 53.87 | 0.0508 |
| 3 | 2.3 | 71.12 | 0.0177 | 8.5 | 11.47 | 27.50 | 0.0379 | 11.4 | 14.45 | 54.71 | 0.0575 |
| 4 | 2.4 | 70.76 | 0.0181 | 8.2 | 11.51 | 27.50 | 0.0368 | 10.5 | 14.64 | 53.78 | 0.0487 |
| 6 | 2.4 | 70.09 | 0.0180 | 8.1 | 11.45 | 27.58 | 0.0366 | 10.4 | 14.75 | 53.50 | 0.0493 |
| 7 | 2.3 | 70.63 | 0.0177 | 8.2 | 11.65 | 27.49 | 0.0369 | 10.4 | 14.62 | 53.76 | 0.0497 |
| 8 | 2.4 | 70.83 | 0.0184 | 8.3 | 11.48 | 27.53 | 0.0372 | 11.4 | 14.21 | 54.07 | 0.0578 |
| 13 | 2.4 | 70.50 | 0.0181 | 8.2 | 11.53 | 27.47 | 0.0369 | 10.3 | 14.41 | 54.29 | 0.0503 |
| 15 | 2.5 | 70.91 | 0.0186 | 8.1 | 11.36 | 27.37 | 0.0364 | 10.5 | 14.59 | 53.39 | 0.0501 |
| 17 | 2.3 | 71.12 | 0.0180 | 8.2 | 11.44 | 27.67 | 0.0372 | 10.2 | 14.44 | 54.11 | 0.0485 |
| 20 | 2.4 | 70.84 | 0.0181 | 8.3 | 11.48 | 27.45 | 0.0375 | 11.5 | 14.19 | 54.20 | 0.0589 |
| 21 | 2.4 | 70.15 | 0.0181 | 8.1 | 11.37 | 27.46 | 0.0366 | 10.6 | 14.62 | 53.55 | 0.0506 |
| 22 | 2.4 | 71.16 | 0.0181 | 8.2 | 11.35 | 27.56 | 0.0369 | 10.3 | 14.37 | 52.82 | 0.0495 |
| 24 | 2.4 | 70.98 | 0.0184 | 8.5 | 11.47 | 27.01 | 0.0376 | 10.9 | 14.21 | 54.45 | 0.0563 |
| 25 | 2.5 | 70.95 | 0.0192 | 8.1 | 11.41 | 27.35 | 0.0365 | 10.3 | 14.35 | 51.12 | 0.0470 |
| 26 | 2.4 | 69.91 | 0.0183 | 8.2 | 11.52 | 27.50 | 0.0373 | 11.4 | 14.16 | 54.33 | 0.0574 |
| 29 | 2.5 | 70.75 | 0.0191 | 8.1 | 11.38 | 27.42 | 0.0364 | 10.3 | 14.52 | 52.24 | 0.0481 |
| 31 | 2.4 | 71.32 | 0.0184 | 8.4 | 11.49 | 27.43 | 0.0376 | 11.2 | 14.45 | 54.35 | 0.0559 |
| 32 | 2.4 | 70.15 | 0.0183 | 8.3 | 11.38 | 27.69 | 0.0379 | 11.4 | 14.30 | 53.88 | 0.0570 |
| 33 | 2.4 | 71.55 | 0.0185 | 8.2 | 11.49 | 27.45 | 0.0370 | 10.6 | 15.05 | 52.43 | 0.0487 |
| 37 | 2.3 | 70.30 | 0.0173 | 8.2 | 11.36 | 27.40 | 0.0370 | 10.4 | 14.35 | 54.47 | 0.0500 |
| 39 | 2.3 | 71.16 | 0.0179 | 8.5 | 11.41 | 27.51 | 0.0382 | 11.5 | 14.37 | 54.57 | 0.0563 |
| 41 | 2.4 | 71.10 | 0.0178 | 8.3 | 11.30 | 27.39 | 0.0370 | 10.3 | 14.71 | 53.22 | 0.0488 |
| 45 | 2.4 | 70.84 | 0.0185 | 8.1 | 11.52 | 27.61 | 0.0366 | 10.6 | 14.33 | 51.92 | 0.0494 |
| 46 | 2.4 | 70.70 | 0.0186 | 8.4 | 11.47 | 26.82 | 0.0367 | 11.5 | 14.13 | 53.72 | 0.0588 |
| 49 | 2.3 | 71.63 | 0.0182 | 8.2 | 11.50 | 27.34 | 0.0366 | 10.8 | 14.75 | 53.37 | 0.0505 |
| 50 | 2.4 | 70.62 | 0.0184 | 8.3 | 11.35 | 27.44 | 0.0374 | 11.1 | 14.18 | 54.28 | 0.0573 |
| 54 | 2.4 | 71.16 | 0.0182 | 8.4 | 11.74 | 27.32 | 0.0374 | 11.1 | 14.18 | 54.69 | 0.0581 |
| 55 | 2.3 | 70.58 | 0.0171 | 8.5 | 11.45 | 27.69 | 0.0383 | 11.1 | 13.95 | 54.45 | 0.0581 |
| 56 | 2.3 | 70.80 | 0.0176 | 8.3 | 11.32 | 27.42 | 0.0370 | 10.4 | 14.66 | 54.52 | 0.0498 |
| 61 | 2.4 | 70.34 | 0.0182 | 8.2 | 11.41 | 27.51 | 0.0369 | 10.3 | 14.57 | 53.65 | 0.0487 |
| 62 | 2.5 | 70.91 | 0.0190 | 8.4 | 11.54 | 27.13 | 0.0372 | 11.1 | 14.24 | 54.34 | 0.0568 |
| 64 | 2.4 | 70.33 | 0.0181 | 8.2 | 11.39 | 27.33 | 0.0364 | 10.6 | 14.87 | 52.94 | 0.0489 |
| 66 | 2.4 | 70.71 | 0.0182 | 8.5 | 11.43 | 27.28 | 0.0378 | 11.2 | 14.16 | 53.59 | 0.0562 |
| 67 | 2.4 | 71.09 | 0.0188 | 8.1 | 11.52 | 27.23 | 0.0360 | 10.5 | 14.43 | 52.34 | 0.0498 |
| 70 | 2.3 | 70.71 | 0.0180 | 8.5 | 11.54 | 27.45 | 0.0382 | 10.8 | 14.16 | 54.53 | 0.0557 |
| 71 | 2.3 | 71.12 | 0.0174 | 8.1 | 11.40 | 27.56 | 0.0367 | 10.5 | 14.66 | 52.36 | 0.0496 |
| 72 | 2.4 | 71.04 | 0.0185 | 8.4 | 11.46 | 27.30 | 0.0374 | 11.1 | 13.82 | 53.56 | 0.0579 |
| 73 | 2.4 | 71.12 | 0.0186 | 8.1 | 11.36 | 27.47 | 0.0365 | 10.8 | 15.02 | 52.76 | 0.0500 |
| 75 | 2.4 | 71.19 | 0.0182 | 8.2 | 11.43 | 27.34 | 0.0364 | 10.8 | 14.50 | 52.49 | 0.0507 |
| 80 | 2.4 | 71.14 | 0.0183 | 8.1 | 11.46 | 27.37 | 0.0365 | 10.6 | 14.38 | 52.54 | 0.0504 |
| 82 | 2.4 | 71.04 | 0.0188 | 8.1 | 11.41 | 27.36 | 0.0365 | 10.5 | 14.76 | 53.49 | 0.0496 |
| 83 | 2.3 | 70.31 | 0.0177 | 8.3 | 11.59 | 27.58 | 0.0374 | 10.8 | 14.85 | 52.95 | 0.0487 |
| 84 | 2.3 | 70.23 | 0.0179 | 8.3 | 11.38 | 27.43 | 0.0372 | 10.5 | 14.34 | 52.64 | 0.0475 |
| 85 | 2.4 | 71.09 | 0.0183 | 8.4 | 11.47 | 27.60 | 0.0381 | 11.0 | 13.84 | 53.76 | 0.0560 |
| 89 | 2.4 | 70.98 | 0.0181 | 8.5 | 11.47 | 27.26 | 0.0377 | 11.1 | 14.14 | 53.94 | 0.0571 |
| 90 | 2.4 | 70.95 | 0.0185 | 8.3 | 11.44 | 27.45 | 0.0374 | 11.5 | 14.44 | 54.63 | 0.0569 |
| 96 | 2.3 | 70.49 | 0.0176 | 8.2 | 11.48 | 27.41 | 0.0368 | 10.7 | 14.79 | 54.61 | 0.0515 |
| 97 | 2.4 | 70.20 | 0.0186 | 8.4 | 11.51 | 27.16 | 0.0376 | 11.4 | 14.26 | 54.88 | 0.0574 |
| 98 | 2.4 | 70.93 | 0.0184 | 8.2 | 11.36 | 27.48 | 0.0367 | 10.5 | 14.72 | 52.75 | 0.0494 |
| 99 | 2.3 | 70.66 | 0.0179 | 8.1 | 11.63 | 27.38 | 0.0364 | 10.7 | 14.67 | 53.62 | 0.0510 |
| Mean | 2.38 | 70.79 | 0.0182 | 8.3 | 11.45 | 27.42 | 0.0371 | 10.8 | 14.44 | 53.61 | 0.0526 |
| Std Dev | 0.06 | 0.40 | 0.0004 | 0.1 | 0.09 | 0.16 | 0.0006 | 0.4 | 0.28 | 0.86 | 0.0039 |
| Coef Var | 2.4% | 0.6% | 2.4% | 1.7% | 0.8% | 0.6% | 1.5% | 3.8% | 1.9% | 1.6% | 7.4% |

| | B-747P | KC-10 | | | Throughput | | | Timeliness | | Factor Scores | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Random Stream | Use Rate | Use Rate | Average Payload | MTM/D | Outsize Tons | Pax | Cargo Tons | Percent Ontime | Days Late | 1 | 2 | 3 | 4 | 5 |
| 1 | 4.8 | 1.3 | 42.47 | 0.0048 | 7516 | 56539 | 70933 | 84.41 | 0.70 | -0.6 | -0.5 | 0.1 | 2.3 | -2.0 |
| 3 | 4.9 | 1.2 | 42.80 | 0.0048 | 7590 | 56882 | 74317 | 84.02 | 0.69 | 1.2 | -0.8 | -0.8 | 2.7 | 0.3 |
| 4 | 4.7 | 1.2 | 43.14 | 0.0048 | 7592 | 56295 | 71021 | 84.11 | 0.68 | -0.8 | -1.0 | 0.1 | 2.5 | 0.3 |
| 6 | 4.9 | 1.6 | 41.76 | 0.0054 | 7481 | 56350 | 70879 | 84.24 | 0.67 | -0.9 | 0.8 | -0.4 | 0.6 | -2.3 |
| 7 | 4.8 | 1.2 | 41.16 | 0.0047 | 7619 | 56302 | 71051 | 84.39 | 0.67 | -0.7 | -0.5 | -1.4 | -0.1 | 1.3 |
| 8 | 4.8 | 1.6 | 41.29 | 0.0054 | 7565 | 56986 | 74323 | 84.42 | 0.67 | 0.9 | 0.9 | -0.1 | 0.0 | -0.1 |
| 13 | 4.9 | 1.1 | 43.77 | 0.0041 | 7613 | 56469 | 71036 | 84.51 | 0.67 | -0.2 | -2.6 | 0.7 | -0.4 | -0.8 |
| 15 | 4.8 | 1.4 | 41.56 | 0.0051 | 7599 | 56280 | 71022 | 84.64 | 0.67 | -1.0 | -0.1 | 1.2 | -0.8 | 0.0 |
| 17 | 4.9 | 1.3 | 41.71 | 0.0046 | 7563 | 56349 | 71001 | 84.70 | 0.67 | -0.6 | -0.5 | -1.4 | -1.4 | 0.0 |
| 20 | 4.9 | 1.5 | 41.45 | 0.0049 | 7569 | 57218 | 74289 | 84.56 | 0.68 | 1.2 | 0.2 | 0.0 | -0.3 | -0.3 |
| 21 | 4.8 | 1.3 | 41.83 | 0.0046 | 7574 | 56470 | 71016 | 84.43 | 0.67 | -0.6 | -0.7 | 0.1 | -0.2 | -1.2 |
| 22 | 4.9 | 1.3 | 41.37 | 0.0045 | 7583 | 56399 | 71011 | 84.47 | 0.67 | -0.8 | -0.1 | -0.3 | -0.8 | 0.1 |
| 24 | 4.9 | 1.4 | 42.41 | 0.0052 | 7555 | 56946 | 74307 | 84.38 | 0.68 | 1.1 | -0.7 | 1.3 | 1.1 | 0.0 |
| 25 | 5.0 | 1.7 | 41.64 | 0.0060 | 7635 | 56343 | 71076 | 84.38 | 0.67 | -1.2 | 1.6 | 2.0 | -0.5 | 0.0 |
| 26 | 5.0 | 1.7 | 40.73 | 0.0057 | 7533 | 56718 | 74233 | 84.40 | 0.67 | 1.0 | 1.3 | -0.1 | -0.8 | -2.2 |
| 29 | 5.1 | 1.7 | 41.20 | 0.0057 | 7546 | 56607 | 70996 | 84.42 | 0.67 | -1.0 | 1.4 | 1.8 | -1.0 | -1.6 |
| 31 | 4.9 | 1.4 | 42.20 | 0.0051 | 7590 | 57068 | 74308 | 84.43 | 0.67 | 0.9 | -0.3 | 0.3 | -0.2 | 0.5 |
| 32 | 5.0 | 1.5 | 41.58 | 0.0050 | 7617 | 57030 | 74350 | 84.45 | 0.67 | 1.3 | 0.2 | -0.2 | -1.4 | -1.8 |
| 33 | 4.9 | 1.4 | 40.07 | 0.0046 | 7551 | 56411 | 70977 | 84.46 | 0.67 | -1.2 | 0.6 | -0.3 | -0.9 | 1.6 |
| 37 | 4.8 | 1.2 | 42.19 | 0.0047 | 7545 | 56268 | 70977 | 84.50 | 0.67 | -0.3 | -1.1 | -1.2 | 0.0 | -1.2 |
| 39 | 4.8 | 1.3 | 41.11 | 0.0046 | 7689 | 57088 | 74390 | 84.49 | 0.67 | 1.4 | -0.4 | -1.3 | -0.9 | 1.8 |
| 41 | 4.8 | 1.4 | 41.38 | 0.0047 | 7552 | 56469 | 70978 | 84.47 | 0.67 | -0.8 | 0.0 | -0.5 | -0.1 | 0.2 |
| 45 | 4.9 | 1.4 | 41.52 | 0.0050 | 7636 | 56359 | 71060 | 84.47 | 0.67 | -0.9 | 0.4 | 0.1 | -0.9 | 0.6 |
| 46 | 4.9 | 1.4 | 41.78 | 0.0051 | 7658 | 57300 | 74388 | 84.46 | 0.67 | 1.3 | -0.9 | 2.3 | -0.3 | 0.9 |
| 49 | 4.9 | 1.3 | 42.36 | 0.0046 | 7592 | 56190 | 71008 | 84.47 | 0.67 | -0.9 | -0.9 | -0.2 | -0.2 | 1.7 |
| 50 | 4.7 | 1.6 | 41.47 | 0.0058 | 7567 | 56782 | 74293 | 84.45 | 0.68 | 0.7 | 1.2 | -0.1 | 1.1 | -0.5 |
| 54 | 4.8 | 1.7 | 41.87 | 0.0057 | 7593 | 56900 | 74267 | 84.42 | 0.68 | 1.0 | 0.9 | 0.1 | 1.2 | 1.5 |
| 55 | 4.9 | 1.4 | 40.87 | 0.0048 | 7600 | 57295 | 74324 | 84.39 | 0.68 | 1.7 | 0.5 | -2.4 | 0.0 | -0.4 |
| 56 | 4.8 | 1.2 | 43.48 | 0.0044 | 7543 | 56184 | 70986 | 84.38 | 0.68 | -0.5 | -1.7 | -0.7 | 1.4 | -0.8 |
| 61 | 4.7 | 1.5 | 41.18 | 0.0051 | 7594 | 56394 | 71036 | 84.37 | 0.68 | -0.8 | 0.6 | -0.5 | 1.0 | -0.2 |
| 62 | 4.9 | 1.5 | 41.66 | 0.0053 | 7622 | 56942 | 74360 | 84.36 | 0.68 | 1.0 | -0.1 | 2.2 | 0.6 | 0.5 |
| 64 | 4.9 | 1.6 | 41.47 | 0.0057 | 7616 | 56629 | 71053 | 84.38 | 0.68 | -0.8 | 0.9 | 0.3 | 0.6 | -0.4 |
| 66 | 4.9 | 1.8 | 41.71 | 0.0061 | 7644 | 57063 | 74358 | 84.38 | 0.68 | 1.2 | 1.6 | 0.2 | 0.7 | 0.2 |
| 67 | 4.9 | 1.5 | 41.14 | 0.0052 | 7553 | 56357 | 70995 | 84.40 | 0.68 | -1.2 | 0.7 | 1.2 | 0.6 | 0.7 |
| 70 | 4.9 | 1.4 | 42.69 | 0.0053 | 7604 | 57323 | 74331 | 84.40 | 0.68 | 1.5 | -0.3 | -0.7 | 0.7 | -0.1 |
| 71 | 4.9 | 1.8 | 40.88 | 0.0061 | 7583 | 56113 | 71001 | 84.43 | 0.68 | -1.2 | 2.7 | -2.0 | 0.6 | 0.6 |
| 72 | 4.8 | 1.5 | 42.28 | 0.0051 | 7579 | 57030 | 74284 | 84.40 | 0.68 | 1.0 | 0.1 | 0.8 | 1.0 | 0.2 |
| 73 | 4.9 | 1.3 | 42.11 | 0.0047 | 7609 | 56763 | 71037 | 84.41 | 0.68 | -0.9 | -0.5 | 0.8 | 0.2 | 0.4 |
| 75 | 4.8 | 1.2 | 40.77 | 0.0042 | 7553 | 56358 | 70984 | 84.43 | 0.68 | -1.0 | -0.4 | 0.2 | 0.4 | 1.0 |
| 80 | 4.8 | 1.4 | 41.74 | 0.0050 | 7586 | 56386 | 71013 | 84.44 | 0.68 | -1.0 | 0.3 | 0.4 | 0.7 | 0.8 |
| 82 | 4.9 | 1.3 | 41.42 | 0.0045 | 7593 | 56479 | 71015 | 84.46 | 0.67 | -0.9 | -0.7 | 0.9 | -0.7 | 0.4 |
| 83 | 5.0 | 1.1 | 41.34 | 0.0040 | 7593 | 56445 | 71006 | 84.48 | 0.67 | -0.3 | -1.3 | -1.3 | -1.5 | 0.0 |
| 84 | 4.9 | 1.5 | 42.14 | 0.0054 | 7552 | 56194 | 70982 | 84.51 | 0.67 | -0.5 | 0.4 | -0.9 | -0.4 | -1.3 |
| 85 | 5.0 | 1.4 | 41.51 | 0.0050 | 7597 | 56928 | 74367 | 84.49 | 0.67 | 1.2 | 0.2 | -0.2 | -1.2 | -0.3 |
| 89 | 4.8 | 1.6 | 40.40 | 0.0054 | 7661 | 57176 | 74400 | 84.51 | 0.67 | 1.2 | 1.0 | -0.2 | -0.6 | 1.6 |
| 90 | 4.9 | 1.6 | 41.16 | 0.0056 | 7609 | 56884 | 74314 | 84.51 | 0.67 | 0.9 | 0.8 | 0.1 | -0.8 | 0.2 |
| 96 | 4.9 | 1.1 | 42.43 | 0.0041 | 7576 | 56228 | 71018 | 84.51 | 0.67 | -0.3 | -2.1 | -0.7 | -0.6 | -0.4 |
| 97 | 5.0 | 1.3 | 41.10 | 0.0045 | 7655 | 57125 | 74356 | 84.49 | 0.67 | 1.6 | -1.3 | 1.2 | -1.5 | -0.3 |
| 98 | 5.0 | 1.4 | 41.29 | 0.0049 | 7546 | 56195 | 71003 | 84.49 | 0.67 | -0.9 | 0.2 | 0.2 | -1.0 | -0.6 |
| 99 | 4.8 | 1.4 | 41.40 | 0.0049 | 7627 | 56331 | 71062 | 84.48 | 0.67 | -0.7 | -0.2 | -0.8 | -0.2 | 1.4 |
| Mean | 4.9 | 1.4 | 41.68 | 0.0050 | 7588 | 56637 | 72336 | 84.43 | 0.67 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Std Dev | 0.1 | 0.2 | 0.73 | 0.0005 | 40 | 362 | 1644 | 0.10 | 0.01 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Coef Var | 1.7% | 12.6% | 1.7% | 10.3% | 0.5% | 0.6% | 2.3% | 0.1% | 1.0% | | | | | |

# Appendix C: Large Scenario Random Seed Run Data

The 31 variables used in the analysis of the large scenario random seed runs are presented in this appendix. Each row of data represents the output from one run of AFM with the indicated random stream and the original large scenario file 63. At the bottom of each column of data are the mean, standard deviation, and coefficient of variation for the respective variables. The coefficient of variation is a statistical tool computed by dividing the standard deviation by the mean. In this case, the coefficients of variation are expressed as a percentage of the respective mean values. The relative magnitude of variation caused by changing the AFM initial random seed value, across all variables, can be understood by looking at the coefficients of variation.

The ten factor scores listed in this appendix were computed using the SAS factor analysis procedure, PROC FACTOR, with a varimax rotation. The number of factors selected by the SAS, for this set of 31 variables, was 10. SAS uses the Kaiser criterion (the number of eigenvalues greater than or equal to 1) to determine the number of factors to retain. This default criterion was satisfactory.

| | Throughput | | | C-5A | | | | C-141B | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Random Stream | Outsize Tons | Pax | Cargo Tons | Use Rate | G-Cycle Time | Average Payload | MTM/D | Use Rate | G-Cycle Time | Average Payload | MTM/D |
| 1 | 12743 | 168343 | 119317 | 10.9 | 42.17 | 59.14 | 0.1172 | 12.3 | 34.17 | 21.18 | 0.0434 |
| 3 | 13191 | 165669 | 120217 | 10.9 | 42.37 | 61.30 | 0.1219 | 12.3 | 34.17 | 20.56 | 0.0422 |
| 4 | 13080 | 167957 | 119648 | 10.9 | 42.45 | 60.92 | 0.1206 | 12.5 | 32.96 | 20.46 | 0.0421 |
| 6 | 12646 | 163958 | 120134 | 10.9 | 42.42 | 58.85 | 0.1174 | 12.3 | 34.28 | 20.96 | 0.0427 |
| 7 | 13030 | 165566 | 121287 | 11.0 | 42.60 | 61.41 | 0.1217 | 12.5 | 33.26 | 20.57 | 0.0436 |
| 8 | 12837 | 167083 | 120264 | 11.0 | 42.13 | 59.32 | 0.1182 | 12.3 | 33.61 | 21.21 | 0.0430 |
| 13 | 12720 | 168513 | 120211 | 11.0 | 42.61 | 60.39 | 0.1207 | 12.5 | 33.12 | 20.72 | 0.0428 |
| 15 | 13058 | 166858 | 120850 | 10.9 | 42.27 | 61.19 | 0.1215 | 12.4 | 33.81 | 20.49 | 0.0424 |
| 17 | 12901 | 168331 | 120855 | 11.0 | 42.24 | 60.90 | 0.1217 | 12.5 | 33.43 | 20.19 | 0.0418 |
| 20 | 12463 | 171712 | 119419 | 10.9 | 42.54 | 59.78 | 0.1186 | 12.4 | 33.06 | 20.69 | 0.0426 |
| 21 | 13207 | 164803 | 121201 | 11.0 | 42.15 | 60.81 | 0.1215 | 12.5 | 33.34 | 20.39 | 0.0423 |
| 22 | 12604 | 171992 | 119632 | 10.9 | 42.37 | 59.24 | 0.1181 | 12.4 | 32.93 | 21.26 | 0.0432 |
| 24 | 12576 | 167000 | 120561 | 10.9 | 42.54 | 61.00 | 0.1216 | 12.5 | 33.41 | 20.45 | 0.0424 |
| 25 | 13161 | 164872 | 120008 | 11.0 | 42.39 | 61.21 | 0.1209 | 12.4 | 33.62 | 20.72 | 0.0427 |
| 26 | 12798 | 170357 | 119612 | 10.9 | 42.35 | 59.26 | 0.1186 | 12.5 | 33.15 | 20.79 | 0.0427 |
| 29 | 12593 | 167363 | 120069 | 10.9 | 42.37 | 58.74 | 0.1166 | 12.4 | 33.15 | 20.97 | 0.0431 |
| 31 | 12606 | 166008 | 118747 | 10.9 | 42.58 | 59.05 | 0.1164 | 12.3 | 34.01 | 21.06 | 0.0431 |
| 32 | 12984 | 167902 | 119691 | 10.9 | 42.89 | 61.32 | 0.1204 | 12.4 | 33.64 | 20.64 | 0.0426 |
| 33 | 12693 | 171863 | 119978 | 10.9 | 42.68 | 60.38 | 0.1195 | 12.4 | 34.03 | 20.66 | 0.0425 |
| 37 | 13115 | 165774 | 120968 | 11.0 | 42.35 | 61.69 | 0.1214 | 12.4 | 33.26 | 20.45 | 0.0424 |
| 39 | 12918 | 166929 | 119743 | 10.9 | 42.53 | 60.33 | 0.1200 | 12.3 | 34.24 | 20.25 | 0.0417 |
| 41 | 12812 | 167922 | 119001 | 11.0 | 42.17 | 58.97 | 0.1179 | 12.5 | 33.72 | 20.67 | 0.0423 |
| 45 | 12553 | 166439 | 119910 | 10.9 | 42.47 | 60.04 | 0.1202 | 12.4 | 33.36 | 20.51 | 0.0420 |
| 46 | 12566 | 164743 | 119347 | 10.9 | 42.48 | 59.70 | 0.1187 | 12.5 | 33.17 | 20.62 | 0.0422 |
| 49 | 13220 | 171401 | 121054 | 11.0 | 42.48 | 61.07 | 0.1222 | 12.2 | 34.76 | 20.72 | 0.0422 |
| 50 | 12578 | 169688 | 119326 | 10.9 | 42.75 | 60.08 | 0.1187 | 12.4 | 33.31 | 20.49 | 0.0423 |
| 54 | 12918 | 174773 | 121003 | 10.9 | 42.30 | 61.79 | 0.1225 | 12.4 | 33.17 | 20.57 | 0.0422 |
| 55 | 12763 | 167894 | 119409 | 10.9 | 42.27 | 58.65 | 0.1171 | 12.4 | 33.64 | 20.88 | 0.0428 |
| 56 | 13187 | 164553 | 120918 | 10.9 | 42.76 | 61.56 | 0.1225 | 12.4 | 33.65 | 20.54 | 0.0423 |
| 61 | 12473 | 166029 | 118444 | 10.9 | 42.82 | 59.13 | 0.1168 | 12.5 | 32.57 | 20.56 | 0.0424 |
| 62 | 13115 | 166726 | 120202 | 11.0 | 42.54 | 61.04 | 0.1217 | 12.5 | 33.34 | 20.52 | 0.0422 |
| 64 | 13112 | 176542 | 120273 | 10.9 | 42.18 | 61.43 | 0.1216 | 12.5 | 32.94 | 20.56 | 0.0429 |
| 66 | 12467 | 169722 | 119979 | 10.9 | 42.54 | 59.12 | 0.1179 | 12.4 | 33.41 | 20.91 | 0.0427 |
| 67 | 13327 | 168883 | 120510 | 10.9 | 42.98 | 60.49 | 0.1196 | 12.4 | 33.23 | 20.62 | 0.0427 |
| 70 | 13231 | 163733 | 120496 | 11.0 | 42.39 | 60.86 | 0.1212 | 12.5 | 33.47 | 20.48 | 0.0425 |
| 71 | 12573 | 164588 | 118799 | 10.9 | 42.68 | 58.78 | 0.1160 | 12.4 | 33.49 | 20.93 | 0.0434 |
| 72 | 12579 | 169230 | 118809 | 10.9 | 42.62 | 58.81 | 0.1162 | 12.3 | 34.11 | 20.80 | 0.0426 |
| 73 | 12904 | 169845 | 119534 | 10.9 | 42.53 | 60.79 | 0.1199 | 12.4 | 33.91 | 20.29 | 0.0416 |
| 75 | 12606 | 168530 | 118503 | 10.9 | 42.30 | 58.92 | 0.1167 | 12.2 | 33.95 | 20.91 | 0.0424 |
| 80 | 12564 | 167822 | 120050 | 10.9 | 42.39 | 59.09 | 0.1175 | 12.3 | 34.09 | 20.98 | 0.0431 |
| 82 | 12605 | 175246 | 120378 | 10.9 | 42.44 | 60.15 | 0.1192 | 12.4 | 33.87 | 20.58 | 0.0424 |
| 83 | 12409 | 169628 | 120194 | 11.0 | 42.40 | 60.01 | 0.1204 | 12.4 | 33.47 | 20.51 | 0.0422 |
| 84 | 12412 | 163843 | 119243 | 10.9 | 42.32 | 59.96 | 0.1185 | 12.3 | 33.53 | 20.72 | 0.0422 |
| 85 | 12390 | 170569 | 120085 | 11.0 | 42.31 | 59.78 | 0.1198 | 12.4 | 33.09 | 20.58 | 0.0428 |
| 89 | 12845 | 167508 | 120572 | 10.9 | 42.56 | 60.73 | 0.1202 | 12.3 | 34.46 | 20.60 | 0.0426 |
| 90 | 12568 | 178478 | 119376 | 10.9 | 42.44 | 59.23 | 0.1170 | 12.4 | 33.41 | 20.88 | 0.0429 |
| 96 | 12732 | 172946 | 120186 | 11.0 | 42.33 | 60.69 | 0.1219 | 12.4 | 33.70 | 20.62 | 0.0420 |
| 97 | 13027 | 167217 | 120745 | 10.9 | 42.58 | 61.14 | 0.1214 | 12.5 | 33.46 | 20.58 | 0.0424 |
| 98 | 12576 | 171482 | 120033 | 11.0 | 42.30 | 60.24 | 0.1206 | 12.5 | 32.90 | 20.57 | 0.0428 |
| 99 | 12480 | 168712 | 119747 | 10.9 | 42.57 | 59.82 | 0.1197 | 12.5 | 32.90 | 20.66 | 0.0425 |
| Mean | 12790 | 168471 | 119971 | 10.93 | 42.46 | 60.17 | 0.1196 | 12.40 | 33.53 | 20.67 | 0.0425 |
| Std Dev | 266.9 | 3289.5 | 708.3 | 0.05 | 0.19 | 0.94 | 0.0019 | 0.08 | 0.46 | 0.23 | 0.0004 |
| Coef Var | 2.1% | 2.0% | 0.6% | 0.4% | 0.5% | 1.6% | 1.6% | 0.7% | 1.4% | 1.1% | 1.0% |

| | C-17 | | | | KC-10 | | | | B-747 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Random Stream | Use Rate | G-Cycle Time | Avg Payload | MTM/D | Use Rate | G-Cycle Time | Avg Payload | MTM/D | Use Rate | G-Cycle Time | Avg Payload | MTM/D |
| 1 | 14.7 | 22.70 | 43.19 | 0.1130 | 12.7 | 29.28 | 33.15 | 0.0885 | 9.4 | 36.34 | 65.40 | 0.1253 |
| 3 | 14.8 | 22.60 | 43.43 | 0.1135 | 12.5 | 29.79 | 32.63 | 0.0854 | 9.4 | 35.95 | 64.72 | 0.1235 |
| 4 | 14.7 | 22.92 | 42.77 | 0.1117 | 12.6 | 29.60 | 32.01 | 0.0857 | 9.5 | 36.06 | 64.41 | 0.1250 |
| 6 | 14.7 | 22.75 | 44.27 | 0.1157 | 12.7 | 29.18 | 32.85 | 0.0875 | 9.5 | 36.01 | 65.80 | 0.1280 |
| 7 | 14.7 | 22.79 | 43.09 | 0.1123 | 12.7 | 29.05 | 35.00 | 0.0935 | 9.4 | 36.28 | 65.66 | 0.1258 |
| 8 | 14.8 | 22.59 | 44.27 | 0.1161 | 12.7 | 29.70 | 32.98 | 0.0880 | 9.4 | 36.87 | 65.12 | 0.1236 |
| 13 | 14.6 | 23.66 | 42.10 | 0.1099 | 12.7 | 29.08 | 35.27 | 0.0936 | 9.4 | 36.46 | 65.47 | 0.1245 |
| 15 | 14.7 | 22.68 | 42.46 | 0.1113 | 12.7 | 28.93 | 34.56 | 0.0915 | 9.4 | 36.51 | 65.69 | 0.1248 |
| 17 | 14.7 | 22.53 | 42.79 | 0.1120 | 12.6 | 29.68 | 34.32 | 0.0909 | 9.4 | 36.51 | 65.24 | 0.1255 |
| 20 | 14.6 | 23.06 | 42.64 | 0.1116 | 12.6 | 29.71 | 34.25 | 0.0896 | 9.3 | 37.11 | 65.49 | 0.1242 |
| 21 | 14.7 | 23.17 | 42.76 | 0.1122 | 12.6 | 29.28 | 35.23 | 0.0930 | 9.4 | 35.93 | 65.44 | 0.1253 |
| 22 | 14.6 | 23.49 | 42.99 | 0.1131 | 12.6 | 29.11 | 33.14 | 0.0881 | 9.4 | 36.38 | 64.63 | 0.1241 |
| 24 | 14.7 | 22.78 | 42.90 | 0.1124 | 12.5 | 29.70 | 33.64 | 0.0888 | 9.4 | 37.06 | 64.39 | 0.1245 |
| 25 | 14.7 | 22.98 | 42.35 | 0.1104 | 12.6 | 29.56 | 33.36 | 0.0885 | 9.5 | 36.15 | 65.03 | 0.1251 |
| 26 | 14.7 | 22.55 | 43.30 | 0.1139 | 12.5 | 30.28 | 33.17 | 0.0873 | 9.4 | 36.13 | 64.65 | 0.1227 |
| 29 | 14.6 | 23.44 | 43.32 | 0.1141 | 12.7 | 29.43 | 33.78 | 0.0896 | 9.4 | 37.12 | 65.80 | 0.1270 |
| 31 | 14.6 | 23.23 | 43.48 | 0.1144 | 12.7 | 28.95 | 32.11 | 0.0862 | 9.4 | 35.84 | 65.47 | 0.1256 |
| 32 | 14.6 | 23.34 | 42.53 | 0.1112 | 12.7 | 29.06 | 33.61 | 0.0903 | 9.4 | 36.13 | 64.89 | 0.1231 |
| 33 | 14.8 | 22.45 | 43.32 | 0.1134 | 12.6 | 29.35 | 33.61 | 0.0895 | 9.3 | 36.57 | 65.98 | 0.1251 |
| 37 | 14.6 | 23.78 | 42.98 | 0.1124 | 12.6 | 28.98 | 33.48 | 0.0887 | 9.5 | 36.28 | 65.57 | 0.1279 |
| 39 | 14.7 | 22.76 | 42.48 | 0.1112 | 12.6 | 29.70 | 34.97 | 0.0922 | 9.4 | 36.52 | 65.53 | 0.1239 |
| 41 | 14.8 | 22.47 | 43.54 | 0.1137 | 12.6 | 29.69 | 32.88 | 0.0877 | 9.3 | 36.81 | 64.51 | 0.1216 |
| 45 | 14.5 | 23.88 | 43.29 | 0.1133 | 12.7 | 29.34 | 33.90 | 0.0906 | 9.3 | 37.01 | 65.26 | 0.1230 |
| 46 | 14.7 | 22.80 | 42.97 | 0.1128 | 12.4 | 30.37 | 33.55 | 0.0878 | 9.4 | 36.02 | 64.90 | 0.1244 |
| 49 | 14.7 | 23.25 | 42.64 | 0.1121 | 12.7 | 28.76 | 35.52 | 0.0965 | 9.4 | 36.65 | 64.31 | 0.1217 |
| 50 | 14.6 | 23.79 | 42.34 | 0.1115 | 12.7 | 28.86 | 33.59 | 0.0899 | 9.4 | 36.89 | 65.36 | 0.1248 |
| 54 | 14.7 | 23.02 | 43.65 | 0.1146 | 12.7 | 28.96 | 32.58 | 0.0865 | 9.4 | 36.75 | 65.27 | 0.1248 |
| 55 | 14.8 | 22.68 | 43.37 | 0.1131 | 12.5 | 29.92 | 35.13 | 0.0922 | 9.5 | 36.32 | 64.72 | 0.1232 |
| 56 | 14.7 | 23.14 | 42.94 | 0.1125 | 12.7 | 29.37 | 34.18 | 0.0912 | 9.4 | 37.17 | 65.09 | 0.1254 |
| 61 | 14.6 | 23.79 | 42.31 | 0.1105 | 12.7 | 29.07 | 33.54 | 0.0894 | 9.5 | 36.29 | 65.20 | 0.1248 |
| 62 | 14.7 | 22.64 | 42.95 | 0.1123 | 12.7 | 29.05 | 33.71 | 0.0899 | 9.3 | 36.68 | 64.51 | 0.1224 |
| 64 | 14.7 | 23.18 | 42.17 | 0.1106 | 12.6 | 29.69 | 33.41 | 0.0890 | 9.4 | 36.01 | 65.50 | 0.1249 |
| 66 | 14.7 | 23.25 | 43.95 | 0.1151 | 12.6 | 29.51 | 33.23 | 0.0886 | 9.4 | 36.57 | 65.54 | 0.1270 |
| 67 | 14.7 | 22.77 | 43.02 | 0.1119 | 12.6 | 29.99 | 35.07 | 0.0931 | 9.6 | 35.72 | 65.19 | 0.1272 |
| 70 | 14.7 | 22.77 | 42.89 | 0.1120 | 12.6 | 29.21 | 33.77 | 0.0897 | 9.5 | 36.34 | 64.85 | 0.1243 |
| 71 | 14.6 | 23.42 | 42.78 | 0.1131 | 12.6 | 29.15 | 33.77 | 0.0895 | 9.3 | 37.39 | 64.39 | 0.1232 |
| 72 | 14.6 | 23.17 | 43.48 | 0.1136 | 12.6 | 29.33 | 33.09 | 0.0887 | 9.4 | 36.88 | 64.90 | 0.1232 |
| 73 | 14.7 | 22.87 | 43.04 | 0.1128 | 12.6 | 29.30 | 32.58 | 0.0855 | 9.4 | 35.94 | 65.00 | 0.1250 |
| 75 | 14.7 | 22.78 | 43.10 | 0.1133 | 12.7 | 29.24 | 32.78 | 0.0870 | 9.4 | 37.09 | 64.73 | 0.1239 |
| 80 | 14.7 | 23.04 | 43.39 | 0.1144 | 12.7 | 28.97 | 33.91 | 0.0909 | 9.4 | 36.18 | 65.27 | 0.1245 |
| 82 | 14.7 | 23.11 | 42.82 | 0.1117 | 12.6 | 29.36 | 34.85 | 0.0925 | 9.5 | 36.77 | 64.33 | 0.1240 |
| 83 | 14.7 | 22.98 | 42.64 | 0.1115 | 12.5 | 30.01 | 34.58 | 0.0915 | 9.4 | 36.36 | 64.76 | 0.1233 |
| 84 | 14.7 | 23.05 | 42.57 | 0.1111 | 12.5 | 30.22 | 34.81 | 0.0913 | 9.4 | 36.22 | 64.90 | 0.1235 |
| 85 | 14.6 | 23.48 | 42.53 | 0.1115 | 12.7 | 29.40 | 35.47 | 0.0944 | 9.4 | 35.89 | 64.74 | 0.1224 |
| 89 | 14.7 | 23.19 | 42.90 | 0.1122 | 12.6 | 29.36 | 34.49 | 0.0920 | 9.5 | 36.12 | 66.00 | 0.1272 |
| 90 | 14.6 | 23.19 | 43.72 | 0.1142 | 12.6 | 29.51 | 32.78 | 0.0868 | 9.4 | 36.29 | 65.21 | 0.1246 |
| 96 | 14.8 | 22.47 | 42.85 | 0.1116 | 12.5 | 30.00 | 33.47 | 0.0885 | 9.5 | 35.75 | 64.90 | 0.1258 |
| 97 | 14.6 | 23.18 | 42.92 | 0.1124 | 12.7 | 29.07 | 35.16 | 0.0942 | 9.4 | 36.57 | 64.79 | 0.1236 |
| 98 | 14.6 | 23.55 | 42.69 | 0.1117 | 12.6 | 29.04 | 34.08 | 0.0902 | 9.3 | 37.66 | 64.65 | 0.1219 |
| 99 | 14.7 | 22.80 | 43.11 | 0.1124 | 12.6 | 29.79 | 33.67 | 0.0896 | 9.4 | 36.43 | 65.31 | 0.1256 |
| Mean | 14.68 | 23.04 | 43.00 | 0.1126 | 12.62 | 29.42 | 33.81 | 0.0898 | 9.41 | 36.46 | 65.09 | 0.1245 |
| Std Dev | 0.07 | 0.38 | 0.49 | 0.0013 | 0.08 | 0.39 | 0.91 | 0.0025 | 0.06 | 0.45 | 0.45 | 0.0015 |
| Coef Var | 0.5% | 1.7% | 1.1% | 1.2% | 0.6% | 1.3% | 2.7% | 2.8% | 0.7% | 1.2% | 0.7% | 1.2% |

| | B-747P | | DC-8 | | | | Timeliness | | Factor Scores | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Random Stream | Use Rate | G-Cycle Time | Use Rate | G-Cycle Time | Average Payload | MTM/D | Percent Ontime | Days Late | 1 | 2 | 3 | 4 |
| 1 | 9.5 | 46.58 | 9.2 | 37.92 | 17.37 | 0.0314 | 15.38 | 2.58 | -0.790 | -0.047 | 0.256 | -0.118 |
| 3 | 9.5 | 46.23 | 9.6 | 35.27 | 17.72 | 0.0330 | 15.20 | 2.53 | 1.102 | -1.378 | -0.535 | -1.652 |
| 4 | 9.5 | 46.08 | 9.2 | 37.37 | 17.66 | 0.0306 | 14.87 | 2.49 | 0.700 | -0.162 | -0.265 | -2.067 |
| 6 | 9.4 | 46.92 | 9.3 | 37.44 | 17.38 | 0.0318 | 15.03 | 2.51 | -0.162 | 0.210 | -1.133 | -1.264 |
| 7 | 9.5 | 45.99 | 9.3 | 36.16 | 17.47 | 0.0313 | 14.84 | 2.48 | 1.740 | 0.675 | -0.459 | 1.044 |
| 8 | 9.5 | 46.49 | 9.4 | 35.20 | 17.37 | 0.0319 | 15.04 | 2.51 | 0.571 | -0.939 | -0.325 | -0.695 |
| 13 | 9.5 | 45.54 | 9.5 | 35.14 | 17.44 | 0.0315 | 14.78 | 2.52 | 0.067 | 1.218 | 0.234 | 1.900 |
| 15 | 9.5 | 46.75 | 9.2 | 36.45 | 17.22 | 0.0307 | 14.79 | 2.53 | 1.156 | 0.340 | -0.063 | 0.520 |
| 17 | 9.6 | 45.82 | 9.5 | 34.81 | 17.39 | 0.0320 | 14.86 | 2.53 | 1.281 | -1.106 | 0.220 | 0.391 |
| 20 | 9.5 | 46.59 | 9.4 | 35.92 | 17.46 | 0.0324 | 14.85 | 2.55 | -1.211 | 0.161 | 0.161 | 0.363 |
| 21 | 9.4 | 47.09 | 9.5 | 35.00 | 17.55 | 0.0314 | 14.93 | 2.51 | 1.596 | -0.462 | -1.177 | 1.182 |
| 22 | 9.7 | 45.01 | 9.5 | 35.64 | 17.25 | 0.0320 | 15.05 | 2.50 | -1.083 | 0.668 | 1.577 | -0.213 |
| 24 | 9.5 | 46.14 | 9.4 | 35.10 | 17.32 | 0.0320 | 15.06 | 2.52 | 0.211 | -0.831 | -0.177 | -0.301 |
| 25 | 9.4 | 46.41 | 9.1 | 38.22 | 17.46 | 0.0312 | 14.90 | 2.51 | 0.814 | -0.262 | -0.649 | -0.018 |
| 26 | 9.5 | 46.01 | 9.3 | 36.87 | 17.30 | 0.0313 | 14.74 | 2.51 | -0.696 | -1.745 | 0.160 | -0.779 |
| 29 | 9.4 | 47.12 | 9.5 | 36.57 | 17.29 | 0.0325 | 14.85 | 2.51 | -1.014 | 0.855 | -0.798 | 0.047 |
| 31 | 9.4 | 47.00 | 9.2 | 37.75 | 17.24 | 0.0315 | 14.86 | 2.52 | -1.158 | 1.201 | -0.638 | -1.516 |
| 32 | 9.5 | 45.48 | 9.3 | 36.21 | 17.40 | 0.0310 | 14.77 | 2.51 | 0.186 | 1.561 | 0.233 | -0.288 |
| 33 | 9.5 | 45.73 | 9.3 | 36.02 | 17.42 | 0.0314 | 14.69 | 2.51 | 0.218 | -0.318 | 0.310 | -0.619 |
| 37 | 9.5 | 47.09 | 9.5 | 35.06 | 17.16 | 0.0315 | 14.71 | 2.52 | 1.301 | 0.870 | -0.537 | -0.247 |
| 39 | 9.4 | 46.58 | 9.1 | 38.80 | 17.13 | 0.0304 | 14.67 | 2.52 | -0.263 | -0.564 | -0.361 | 0.816 |
| 41 | 9.4 | 46.92 | 9.6 | 35.62 | 17.27 | 0.0332 | 14.80 | 2.51 | -0.053 | -1.766 | -0.730 | -0.789 |
| 45 | 9.5 | 46.68 | 9.4 | 36.81 | 17.40 | 0.0323 | 14.85 | 2.51 | -0.375 | 1.449 | -0.441 | -0.313 |
| 46 | 9.4 | 47.15 | 9.3 | 36.56 | 17.42 | 0.0313 | 14.94 | 2.50 | -1.115 | -1.946 | -1.193 | -0.419 |
| 49 | 9.5 | 46.39 | 9.5 | 34.66 | 17.38 | 0.0326 | 15.04 | 2.51 | 1.355 | 0.678 | 0.444 | 2.148 |
| 50 | 9.5 | 46.64 | 9.3 | 36.39 | 17.45 | 0.0314 | 14.97 | 2.51 | -0.716 | 1.877 | -0.007 | -0.149 |
| 54 | 9.7 | 44.59 | 9.5 | 35.12 | 17.52 | 0.0324 | 14.95 | 2.51 | 1.781 | 0.791 | 1.606 | -1.990 |
| 55 | 9.5 | 46.52 | 9.3 | 36.13 | 17.32 | 0.0314 | 14.93 | 2.51 | -1.141 | -1.940 | -0.190 | 1.276 |
| 56 | 9.4 | 46.69 | 9.4 | 34.83 | 17.66 | 0.0320 | 14.94 | 2.51 | 1.429 | 0.985 | -1.233 | -0.276 |
| 61 | 9.4 | 46.33 | 9.4 | 35.42 | 17.25 | 0.0302 | 14.99 | 2.50 | -1.701 | 1.431 | -0.482 | 0.068 |
| 62 | 9.4 | 46.49 | 9.1 | 38.33 | 17.37 | 0.0302 | 15.04 | 2.50 | 1.536 | 0.240 | -0.566 | -0.623 |
| 64 | 9.9 | 42.79 | 9.6 | 35.83 | 17.32 | 0.0327 | 15.01 | 2.49 | 0.572 | -0.213 | 3.294 | 0.062 |
| 66 | 9.5 | 46.42 | 9.7 | 34.42 | 17.47 | 0.0327 | 15.03 | 2.50 | -0.699 | 0.035 | -0.293 | -0.692 |
| 67 | 9.6 | 44.96 | 9.5 | 34.68 | 17.52 | 0.0323 | 14.99 | 2.50 | 0.164 | -0.224 | 0.286 | 0.978 |
| 70 | 9.4 | 47.04 | 9.2 | 37.01 | 17.19 | 0.0305 | 15.00 | 2.49 | 1.332 | -0.401 | -0.975 | -0.026 |
| 71 | 9.4 | 47.44 | 9.3 | 36.49 | 17.21 | 0.0305 | 15.00 | 2.49 | -1.705 | 0.915 | -0.939 | 0.115 |
| 72 | 9.5 | 46.72 | 9.5 | 34.73 | 17.48 | 0.0325 | 15.01 | 2.49 | -1.444 | 0.526 | -0.222 | -0.517 |
| 73 | 9.5 | 46.25 | 9.6 | 34.42 | 17.31 | 0.0320 | 15.04 | 2.50 | 0.321 | -0.204 | 0.087 | -1.682 |
| 75 | 9.5 | 46.14 | 9.5 | 36.00 | 17.39 | 0.0329 | 15.01 | 2.50 | -1.124 | 0.173 | 0.143 | -0.887 |
| 80 | 9.4 | 46.98 | 9.4 | 35.36 | 17.56 | 0.0319 | 15.06 | 2.50 | -0.412 | 0.561 | -0.643 | 0.247 |
| 82 | 9.7 | 44.76 | 9.3 | 36.18 | 17.43 | 0.0316 | 15.11 | 2.50 | -0.314 | -0.124 | 1.819 | 1.112 |
| 83 | 9.5 | 46.05 | 9.3 | 36.17 | 17.06 | 0.0309 | 15.06 | 2.50 | -0.562 | -1.529 | 0.463 | 1.453 |
| 84 | 9.4 | 46.99 | 9.6 | 35.64 | 17.65 | 0.0334 | 15.08 | 2.50 | -1.437 | -1.419 | -1.131 | 1.255 |
| 85 | 9.5 | 45.83 | 9.3 | 37.22 | 17.73 | 0.0318 | 15.07 | 2.50 | -0.298 | 0.396 | 0.294 | 2.014 |
| 89 | 9.5 | 46.67 | 9.5 | 36.01 | 17.18 | 0.0320 | 15.07 | 2.50 | -0.002 | 0.147 | -0.090 | 1.003 |
| 90 | 9.9 | 42.85 | 9.4 | 35.83 | 17.43 | 0.0318 | 15.08 | 2.50 | -1.007 | 0.356 | 3.244 | -1.070 |
| 96 | 9.8 | 44.42 | 9.3 | 36.12 | 17.25 | 0.0299 | 15.09 | 2.49 | 0.534 | -1.966 | 2.072 | 0.090 |
| 97 | 9.5 | 46.52 | 9.4 | 35.31 | 17.52 | 0.0319 | 15.08 | 2.49 | 0.907 | 1.034 | -0.398 | 0.812 |
| 98 | 9.5 | 45.69 | 9.4 | 36.18 | 17.57 | 0.0327 | 15.12 | 2.49 | 0.192 | 0.712 | 0.421 | 0.458 |
| 99 | 9.4 | 46.97 | 9.4 | 36.19 | 17.40 | 0.0322 | 15.17 | 2.49 | -0.589 | -0.520 | -0.674 | -0.144 |
| Mean | 9.51 | 46.17 | 9.39 | 36.05 | 17.39 | 0.0317 | 14.97 | 2.51 | 0.000 | 0.000 | 0.000 | 0.000 |
| Std Dev | 0.12 | 0.98 | 0.14 | 1.05 | 0.15 | 0.0008 | 0.14 | 0.02 | 1.000 | 1.000 | 1.000 | 1.000 |
| Coef Var | 1.3% | 2.1% | 1.5% | 2.9% | 0.9% | 2.6% | 0.9% | 0.7% | | | | |

| | Factor Scores | | | | | |
|---|---|---|---|---|---|---|
| Random Stream | **5** | **6** | **7** | **8** | **9** | **10** |
| 1 | -1.936 | 1.468 | 0.308 | 1.227 | 1.961 | 3.467 |
| 3 | 1.046 | -0.973 | 0.105 | 1.122 | 2.633 | 0.866 |
| 4 | -1.486 | -1.192 | 0.743 | -1.228 | 1.447 | -0.880 |
| 6 | -0.244 | 1.729 | 1.765 | 1.233 | -0.269 | 0.347 |
| 7 | -0.247 | 1.855 | 0.741 | -1.101 | -0.522 | -0.727 |
| 8 | 0.346 | 3.017 | -0.844 | 0.633 | -0.178 | -0.328 |
| 13 | 0.315 | -0.100 | 0.055 | -1.242 | -0.414 | 0.763 |
| 15 | -1.021 | -0.359 | -0.070 | 0.649 | -1.311 | 1.593 |
| 17 | 0.952 | -0.589 | -0.421 | -0.634 | -0.985 | 1.268 |
| 20 | 0.492 | -0.906 | -0.984 | -0.754 | -0.264 | 2.641 |
| 21 | 0.759 | 0.497 | 0.315 | -1.047 | 0.119 | 0.641 |
| 22 | 0.041 | 1.141 | -0.086 | -0.660 | 0.316 | -0.602 |
| 24 | 0.550 | -0.922 | -0.596 | -0.520 | 0.102 | -0.149 |
| 25 | -2.094 | -0.151 | 0.763 | -0.421 | 1.074 | 0.562 |
| 26 | -0.690 | 0.243 | -0.403 | -0.997 | -0.704 | -0.196 |
| 29 | 0.891 | 1.466 | 0.304 | -0.880 | -1.179 | 1.064 |
| 31 | -1.343 | 0.738 | 0.712 | 0.810 | -0.467 | 0.548 |
| 32 | -0.869 | -1.365 | 0.155 | 0.396 | 0.051 | -0.565 |
| 33 | 0.156 | -0.146 | -0.242 | 0.770 | -1.936 | 0.615 |
| 37 | 0.774 | -0.050 | 1.112 | -0.791 | -1.846 | 0.590 |
| 39 | -1.747 | -1.983 | -0.228 | 1.631 | -2.143 | 0.974 |
| 41 | 0.899 | 0.594 | -2.472 | -0.159 | -1.000 | -0.306 |
| 45 | 0.559 | -0.818 | -1.436 | -0.402 | -0.530 | 0.704 |
| 46 | -0.200 | -0.891 | 0.444 | -1.322 | 0.112 | -0.230 |
| 49 | 0.694 | -0.143 | -1.431 | 3.169 | 0.506 | -1.023 |
| 50 | -0.318 | -1.362 | -0.054 | -0.123 | 0.046 | 0.228 |
| 54 | 1.024 | 0.209 | -0.516 | -0.043 | 0.008 | 0.453 |
| 55 | -0.370 | 0.851 | 0.326 | 0.507 | -0.208 | -0.626 |
| 56 | 0.962 | -0.789 | 0.075 | 0.307 | 0.772 | -0.125 |
| 61 | -0.540 | -1.237 | 1.137 | -1.283 | -0.349 | -1.166 |
| 62 | -2.266 | 0.104 | -1.691 | -0.264 | 0.291 | -0.872 |
| 64 | 0.447 | -0.265 | 0.558 | -1.319 | 0.169 | 0.856 |
| 66 | 2.291 | 1.055 | 0.733 | -0.312 | -0.443 | -0.238 |
| 67 | 1.051 | -0.364 | 3.065 | 0.111 | 0.720 | -1.114 |
| 70 | -1.471 | 0.443 | 0.273 | -0.433 | -0.404 | -1.421 |
| 71 | -0.889 | 0.471 | -1.256 | -0.131 | -0.488 | -1.731 |
| 72 | 1.080 | -0.253 | -0.503 | 1.155 | 0.166 | -1.360 |
| 73 | 1.107 | -1.819 | 0.193 | 0.785 | -0.381 | -0.698 |
| 75 | 0.397 | -0.086 | -0.945 | 1.681 | 0.407 | -0.229 |
| 80 | 0.375 | 1.444 | 0.293 | 1.112 | 0.751 | -0.266 |
| 82 | -0.375 | -0.358 | -0.047 | 0.958 | 0.594 | -0.957 |
| 83 | -0.560 | -0.351 | -0.595 | -0.079 | -1.159 | -0.687 |
| 84 | 1.388 | -1.160 | 0.121 | -0.021 | 1.943 | 0.680 |
| 85 | -0.750 | 0.571 | -0.456 | -0.885 | 2.102 | 0.311 |
| 89 | 0.704 | -0.230 | 1.882 | 1.523 | -0.921 | 0.217 |
| 90 | 0.041 | 0.806 | 0.221 | -0.123 | -0.017 | -0.271 |
| 96 | -1.113 | -0.152 | 1.032 | 0.297 | -0.584 | -1.054 |
| 97 | 0.484 | -0.120 | -0.205 | -0.118 | 0.873 | -1.067 |
| 98 | 0.277 | 0.399 | -2.449 | -1.585 | 1.105 | -0.271 |
| 99 | 0.424 | 0.029 | 0.497 | -1.197 | 0.434 | -0.229 |
| Mean | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Std Dev | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| Coef Var | | | | | | |

# Appendix D: Fortran Code for Generating Perturbed Files 63

```
      program screendesign
c
c23456789012345678901234567890123456789012345678901234567890123456789012
c     This program uses a 2^4-1 factorial design to test the relative
c     importance and impact of the four TPFDD (file63) manipulations.
c     The design encompasses 8 runs, where replications for each run
c     can be specified by the user.  The first two changes to the file63
c     are random effects, but will be treated as deterministic effects
c     for this analysis.  All effects are modelled as off(-1) or on (1)
c     in the following design:
c
c     Design point       APOEAPOD   ALDRDD     10% ton inc     out/over prop
c           0               -1         -1           -1               -1
c           1               -1         -1            1                1
c           2               -1          1           -1                1
c           3               -1          1            1               -1
c           4                1         -1           -1                1
c           5                1         -1            1               -1
c           6                1          1           -1               -1
c           7                1          1            1                1
c
c     The modification to the file63 are outlined below:
c       1)  APOEAPOD pairs, for each line, are swapped with a randomly
c           selected pair from the same file63 that has a distance
c           within +/- X% of the original distance.  X for this
c           screening design is determined by the user.  This
c           modification will change the distribution of the cargo but
c           should leave the average MTM/D requirement about the same.
c           This tests the model's sensitivity to varying the cargo
c           distribution between network resources.
c
c       2)  ALD and RDD were adjusted and then the resultant file63
c           were resorted by RDD then by ALD then by a sequence number
c           that reflects where the line was in the original sequence.
c           This sorting keeps all the lines with the same new ALDRDD in
c           the same order as they appeared in the original file63.
c           This tests the model's sensitivity to priorities given to
c           each line.
c
c       3)  Increase all cargo categories and pax by X%.  This reflects
c           a slightly larger increase in rate of deliveries required
c           and attempts to strain the system.  X is user input.
c
c       4)  Double the amount of outsize cargo and subtract an equal
c           amount of tons from the oversize cargo (may spread over
c           several lines if necessary)  This change in proportion of
c           outsize to oversize reflects changes in prepositioning
c           strategies
c
c     Written by:  Capt Glenn G. Rousseau, USAF
c                  AFIT Student, GOA-96M
```

```
c
c     Variable declarations follow:

      integer pcount,loops,i,str,stream(1:99),seed,lines,dayz,
     &        counter,newald,newrdd,ald,rdd,delta
      parameter (lines=2000)
      character f63*80,new1f63*80,new2f63*80,new3f63*80,f25*80,
     &          temp*2,oneline*71,des*80,sortprefix*10,
     &          new4f63*80,new5f63*80,new6f63*80,new7f63*80
      character*8 pairs(1:lines),oldpair,newpair
      real dpct,rnd,out,over,bulk,pax,incout,incover,incbulk,incpax,
     &     carry,spct,pdist(1:lines),out2,over2,incout2,incover2

      f63='f63'
      f25='f25'
      des='screendesign.dat'

      write(*,*) 'Enter integer seed greater than 1:'
      read (*,*) seed
      rnd=rand(seed)

      open (17, file=des, status='new')

      str=0
 21   if (str.eq.99) then
        go to 20
      endif
      str=str+1
      stream(str)=0
      go to 21

 20   call getpairs(pairs,pdist,pcount,lines,f25,f63)
      write(*,*) 'How many replications of the design?'
      read (*,*) loops
      write(*,*) 'Allow distance to vary by how much (value<1.0)?'
      read (*,*) dpct
      write(*,*) 'Maximum number of days around current ALD/RDD?'
      read (*,*) dayz
      write(*,*) 'Strain increase percentage (value<1.0)?'
      read (*,*) spct

      do 10 i=1,loops
        counter=0
        carry=0.0
c
c Get a random stream value (MASS will use this later during execution)
c
 22   rnd=rand(0)
      str=int(rnd*99.0+1.0)
      if(stream(str).eq.1) then
        go to 22
      end if

c
c Save unique stream value in screendesign.dat
c
      stream(str)=1
        write(17,'(i2.2)') str
```

```
      write(temp,'(i2.2)') str
c
c Create filenames with coded extension:  d indicates screening design,
c 1-7 in the next character indicates which run from the screening
c design this file contains, and the last two digits (temp) store
c the random stream to use when executing MASS
c
      new1f63='f63.d1'//temp
      new2f63='f63.d2'//temp
      new3f63='f63.d3'//temp
      new4f63='f63.d4'//temp
      new5f63='f63.d5'//temp
      new6f63='f63.d6'//temp
      new7f63='f63.d7'//temp
c
c Open original file 63
c
      open(63,file=f63,status='old')
c
c Create 7 perturbed files 63 in accordance with experimental design
c
      open(64,file=new1f63,status='new')
      open(65,file=new2f63,status='new')
      open(66,file=new3f63,status='new')
      open(67,file=new4f63,status='new')
      open(68,file=new5f63,status='new')
      open(69,file=new6f63,status='new')
      open(70,file=new7f63,status='new')


c
c Read line from original file 63
c

 11   read (63,'(a71)',end=12) oneline
c
c Get pertinent variables from the oneline read
c
      read (oneline,9999) ald,rdd,oldpair,out,over,bulk,pax

9999 format(t23,2i3,a8,t44,4f7.1)
c
c Randomly select new APOEAPOD pair
c
      newpair=oldpair
      call changeicaos(newpair,pairs,pdist,pcount,lines,dpct)
c
c Randomly select perturbed ALD/RDD dates
c
      rnd=rand(0)
      delta=int(rnd*(2.0*dayz+1.0))-dayz
      newald=ald+delta
      if (newald.lt.0) then
        newald=0
      end if
      newrdd=rdd+delta
      if (newrdd.lt.0) then
        newrdd=0
```

```
      end if
      if (newrdd.gt.999) then
        newrdd=999
      end if
      write(sortprefix,'(i3.3,i3.3,i4.4)') rdd,ald,counter
c
c Compute double the outsize value and subtract from oversize column,
c carrying balances forward, as required.
c
      carry=carry+out
      out2=out*2
      over2=over
      if (carry.le.over2) then
         over2=over2-carry
         carry=0.0
      else
         carry=carry-over2
         over2=0.0
      end if
c
c Compute strained increase for all cargo types
c
      incout=out*(1+spct)
      incover=over*(1+spct)
      incbulk=bulk*(1+spct)
      incpax=float(int(pax*(1+spct)))
      incout2=out2*(1+spct)
      incover2=over2*(1+spct)

      write(64,9997) oneline(1:22),ald,rdd,oldpair,oneline(37:43),
     &    incout2,incover2,incbulk,incpax
      write(65,9998) sortprefix,oneline(1:22),newald,newrdd,oldpair,
     &    oneline(37:43),out2,over2,bulk,pax
      write(66,9998) sortprefix,oneline(1:22),newald,newrdd,oldpair,
     &    oneline(37:43),incout,incover,incbulk,incpax
      write(67,9997) oneline(1:22),ald,rdd,newpair,oneline(37:43),
     &    out2,over2,bulk,pax
      write(68,9997) oneline(1:22),ald,rdd,newpair,oneline(37:43),
     &    incout,incover,incbulk,incpax
      write(69,9998) sortprefix,oneline(1:22),newald,newrdd,newpair,
     &    oneline(37:43),out,over,bulk,pax
      write(70,9998) sortprefix,oneline(1:22),newald,newrdd,newpair,
     &    oneline(37:43),incout2,incover2,incbulk,incpax

 9997 format(a22,2i3,a8,a7,4f7.1)
 9998 format(a10,a22,2i3,a8,a7,4f7.1)

      go to 11
 12   close (63)
      close (64)
      close (65)
      close (66)
      close (67)
      close (68)
      close (69)
      close (70)

      call sortfile(new2f63)
```

```
        call sortfile(new3f63)
        call sortfile(new6f63)
        call sortfile(new7f63)

  10  continue
      close(17)

 1100 format(a43,4f7.1)

      end
c
c
c
c
c
      subroutine sortfile(filename)
      character filename*80,sortprefix*10,oneline*71

        IB = SYSTEM('sort '//filename//' > junk')
        open (64, file='junk', status='old')
        open (63, file=filename, status='old')
  33    read (64,'(a10,a71)',end=34) sortprefix,oneline
        write (63,'(a71)') oneline
        go to 33

  34    close(63)
        close(64)
        IB = SYSTEM('rm junk')
        return
      end
c
c
c
c
c
      subroutine getpairs(pairs,pdist,pcount,lines,f25,f63)
      integer lines,pcount,i
      character*8 pairs(1:lines), pair
      real pdist(1:lines)
      character f63*80, f25*80, oneline*71
      real gcdist
      external gcdist

      open (63, file=f63, status='old')

      pcount=0

 110  read (63,'(a71)', END=113) oneline

c  obtain apoe/apod icao pair

        pair=oneline(29:36)

c  if pair is not stored, store it in pairs array

      i=1

 111  if (i.le.pcount) then
```

```
          if (pairs(i).eq.pair) then
            go to 110
            end if
            i=i+1
          go to 111
          end if
          pcount=pcount+1
          pairs(pcount)=pair
          pdist(pcount)=gcdist(pair,f25)
          go to 110

 113  close (63)
      return
      end
c
c
c
c
c
      real function gcdist(pair,f25)
      integer mog, reg
      character pair*8, f25*80
      real lat1, lon1, lat2, lon2, pi, d2r, arg1, arg2, arg3

      call rdfile25(pair(1:4),lat1,lon1,mog,reg,f25)
      call rdfile25(pair(5:8),lat2,lon2,mog,reg,f25)

      pi=acos(-1.0)
      d2r=pi/180.0
      arg1 = sin(lat1*d2r)*sin(lat2*d2r)
      arg2 = cos(lat1*d2r)*cos(lat2*d2r)*cos((lon2-lon1)*d2r)
      arg3=arg1+arg2
      if (abs(arg3).gt.1.0) then
        arg3=1.0
      end if

      gcdist = 60.0*acos(arg3)/d2r

      return
      end
c
c
c
c
c

      subroutine rdfile25(icao,lat,lon,mog,reg,f25)
      integer mog,deg,reg
      real lat, lon, min
      character*4 icao, f25*80, oneline*54

      open (25, file=f25, status='old')

 200  read (25,'(a54)', END=205) oneline
      if (icao.eq.oneline(1:4)) then

        read(oneline(7:8),'(i2)') reg
```

```
        read(oneline(9:15),'(i3,f4.1)') deg, min
        lat=real(deg)+min/60.0
        if (oneline(16:16).eq.'S') then
          lat= -1.0*lat
        end if

        read(oneline(17:23),'(i3,f4.1)') deg, min
        lon=real(deg)+min/60.0
        if (oneline(24:24).eq.'E') then
          lon= -1.0*lon
        end if

        read(oneline(41:45),'(i5)') mog
        if (mog.gt.100) then
          write(*,*) 'Subroutine rdfile25 message:'
          write(*,*) 'Internally reducing large MOG for ',icao,
     &              ' to 100.'
          mog=100
        end if

        close (25)
        return

      else
        go to 200
      end if

 205  close (25)
      write(*,*) 'Subroutine rdfile25 message:'
      write(*,*) 'ICAO ',icao,' not found in file 25.'
      write(*,*) 'Execution terminated.'
      stop
      end

c
c
c
c
c
      subroutine changeicaos(pair,pairs,pdist,pcount,lines,pct)
      integer lines,pcount,i,choice,ccount,choices(1:200)
      character*8 pair,pairs(1:lines)
      real pdist(1:lines), pct, maxdist, mindist, rnd

      do 300 i=1,pcount
      if (pair.eq.pairs(i)) then
        mindist=pdist(i)*(1.0-pct)
        maxdist=pdist(i)*(1.0+pct)
        go to 301
      end if
 300  continue
```

```
301   ccount=0
      do 302 i=1,pcount
      if ((mindist.le.pdist(i)).and.(maxdist.ge.pdist(i))) then
        ccount=ccount+1
        choices(ccount)=i
      end if
302   continue

303   rnd=rand(0)
      choice=int(rnd*ccount+1.0)
      if ((choice.eq.0).or.(choice.gt.ccount)) then
      go to 303
      end if

      pair=pairs(choice)

      return
      end
```

# Appendix E: Small Scenario Perturbation Run Data

The 20 variables used in the analysis of the small scenario perturbation runs are presented in this appendix. Each row of data represents the output from one run of AFM with the indicated random stream and a perturbed file 63 corresponding to the design point characteristics. At the bottom of each column of data are the mean, standard deviation, and coefficient of variation for the respective variables. The relative magnitude of variation caused by perturbing the file63, can be understood by looking at the coefficients of variation. As compared to relatively low coefficients of variation from random seed effects (See Appendix B), most of the variables seemed to be significantly affected by the file63 perturbations. Note that *total cargo tons throughput* and *percent of shipments delivered ontime* were not affected much by the perturbation schemes (coefficients of variation < 5.0%), indicating their robustness across many different TPFDD profiles.

The four factor scores listed in this appendix were computed using the SAS factor analysis procedure, PROC FACTOR, with a varimax rotation. The number of factors selected by the SAS, using Kaiser's criterion, was 4, which was satisfactory. Loadings matrix interpretation and plots of these factors scores are provided in Chapter IV.

| | | C-5A | | | C-141B | | | | C-17 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Des Pt | Rand Stream | Use Rate | Average Payload | MTM/D | Use Rate | G-Cycle Time | Average Payload | MTM/D | Use Rate | G-Cycle Time | Average Payload | MTM/D |
| 0 | 3 | 2.3 | 71.12 | 0.0177 | 8.5 | 11.47 | 27.50 | 0.0379 | 11.4 | 14.45 | 54.71 | 0.0575 |
| 0 | 13 | 2.4 | 70.50 | 0.0181 | 8.2 | 11.53 | 27.47 | 0.0369 | 10.3 | 14.41 | 54.29 | 0.0503 |
| 0 | 22 | 2.4 | 71.16 | 0.0181 | 8.2 | 11.35 | 27.56 | 0.0369 | 10.3 | 14.37 | 52.82 | 0.0495 |
| 0 | 31 | 2.4 | 71.32 | 0.0184 | 8.4 | 11.49 | 27.43 | 0.0376 | 11.2 | 14.45 | 54.35 | 0.0559 |
| 0 | 41 | 2.4 | 71.10 | 0.0178 | 8.3 | 11.30 | 27.39 | 0.0370 | 10.3 | 14.71 | 53.22 | 0.0488 |
| 0 | 54 | 2.4 | 71.16 | 0.0182 | 8.4 | 11.74 | 27.32 | 0.0374 | 11.1 | 14.18 | 54.69 | 0.0581 |
| 0 | 64 | 2.4 | 70.33 | 0.0181 | 8.2 | 11.39 | 27.33 | 0.0364 | 10.6 | 14.87 | 52.94 | 0.0489 |
| 0 | 72 | 2.4 | 71.04 | 0.0185 | 8.4 | 11.46 | 27.30 | 0.0374 | 11.1 | 13.82 | 53.56 | 0.0579 |
| 0 | 83 | 2.3 | 70.31 | 0.0177 | 8.3 | 11.59 | 27.58 | 0.0374 | 10.8 | 14.85 | 52.95 | 0.0487 |
| 0 | 96 | 2.3 | 70.49 | 0.0176 | 8.2 | 11.48 | 27.41 | 0.0368 | 10.7 | 14.79 | 54.61 | 0.0515 |
| 1 | 2 | 2.8 | 65.95 | 0.0203 | 8.1 | 11.50 | 27.69 | 0.0367 | 11.6 | 14.04 | 47.54 | 0.0506 |
| 1 | 43 | 2.9 | 65.86 | 0.0205 | 8.2 | 11.51 | 27.29 | 0.0365 | 11.5 | 14.18 | 47.99 | 0.0497 |
| 1 | 54 | 2.9 | 66.48 | 0.0209 | 8.3 | 11.54 | 27.07 | 0.0364 | 11.5 | 14.26 | 47.65 | 0.0497 |
| 1 | 58 | 2.8 | 66.25 | 0.0206 | 8.2 | 11.67 | 27.35 | 0.0364 | 11.5 | 14.02 | 47.95 | 0.0505 |
| 1 | 62 | 2.8 | 65.76 | 0.0207 | 8.1 | 11.55 | 27.47 | 0.0364 | 11.6 | 14.23 | 47.58 | 0.0511 |
| 1 | 64 | 2.9 | 65.59 | 0.0205 | 8.2 | 11.56 | 27.24 | 0.0365 | 11.6 | 13.97 | 47.52 | 0.0509 |
| 1 | 72 | 2.8 | 65.49 | 0.0199 | 8.1 | 11.26 | 27.60 | 0.0366 | 11.5 | 14.22 | 48.64 | 0.0504 |
| 1 | 92 | 2.8 | 65.08 | 0.0198 | 8.2 | 11.57 | 27.32 | 0.0368 | 11.6 | 14.12 | 48.70 | 0.0507 |
| 1 | 95 | 2.8 | 65.92 | 0.0204 | 8.4 | 11.56 | 26.72 | 0.0363 | 11.6 | 14.21 | 47.81 | 0.0508 |
| 1 | 99 | 2.8 | 65.67 | 0.0200 | 8.2 | 11.50 | 27.52 | 0.0367 | 11.5 | 14.35 | 48.44 | 0.0494 |
| 2 | 2 | 2.6 | 65.94 | 0.0185 | 7.7 | 11.25 | 27.12 | 0.0339 | 11.5 | 14.05 | 46.63 | 0.0490 |
| 2 | 43 | 2.5 | 65.81 | 0.0176 | 7.7 | 11.29 | 27.03 | 0.0339 | 11.7 | 14.08 | 46.50 | 0.0501 |
| 2 | 54 | 2.6 | 65.14 | 0.0185 | 7.6 | 11.38 | 26.96 | 0.0332 | 11.6 | 13.97 | 47.52 | 0.0499 |
| 2 | 58 | 2.4 | 65.36 | 0.0172 | 7.8 | 11.30 | 27.21 | 0.0346 | 11.7 | 14.19 | 46.09 | 0.0503 |
| 2 | 62 | 2.7 | 65.61 | 0.0188 | 7.8 | 11.43 | 27.08 | 0.0341 | 11.7 | 14.41 | 45.55 | 0.0499 |
| 2 | 64 | 2.5 | 66.25 | 0.0182 | 7.8 | 11.28 | 27.35 | 0.0346 | 11.7 | 14.44 | 45.09 | 0.0489 |
| 2 | 72 | 2.5 | 65.95 | 0.0182 | 7.8 | 11.38 | 27.11 | 0.0341 | 11.7 | 13.96 | 45.85 | 0.0501 |
| 2 | 92 | 2.6 | 65.85 | 0.0187 | 7.7 | 11.35 | 27.06 | 0.0339 | 11.7 | 14.01 | 46.53 | 0.0501 |
| 2 | 95 | 2.6 | 65.36 | 0.0186 | 7.7 | 11.38 | 27.19 | 0.0341 | 11.5 | 14.14 | 46.09 | 0.0482 |
| 2 | 99 | 2.4 | 65.44 | 0.0173 | 7.9 | 11.34 | 26.87 | 0.0342 | 11.7 | 14.33 | 46.90 | 0.0505 |
| 3 | 2 | 2.6 | 71.19 | 0.0199 | 8.8 | 11.33 | 27.81 | 0.0402 | 11.6 | 14.75 | 53.37 | 0.0557 |
| 3 | 43 | 2.5 | 70.68 | 0.0192 | 8.8 | 11.72 | 28.01 | 0.0405 | 11.6 | 14.52 | 53.07 | 0.0555 |
| 3 | 54 | 2.3 | 70.55 | 0.0180 | 9.0 | 11.56 | 28.09 | 0.0412 | 11.6 | 14.82 | 53.17 | 0.0547 |
| 3 | 58 | 2.5 | 70.85 | 0.0191 | 8.9 | 11.55 | 27.76 | 0.0404 | 11.5 | 14.73 | 54.08 | 0.0556 |
| 3 | 62 | 2.6 | 70.59 | 0.0200 | 8.9 | 11.58 | 27.69 | 0.0405 | 11.3 | 14.62 | 53.00 | 0.0542 |
| 3 | 64 | 2.4 | 72.05 | 0.0192 | 8.9 | 11.51 | 28.17 | 0.0411 | 11.3 | 14.65 | 52.60 | 0.0544 |
| 3 | 72 | 2.5 | 71.43 | 0.0196 | 8.9 | 11.54 | 27.81 | 0.0408 | 11.1 | 14.86 | 53.67 | 0.0540 |
| 3 | 92 | 2.5 | 70.41 | 0.0190 | 8.9 | 11.62 | 28.05 | 0.0409 | 11.4 | 14.58 | 53.81 | 0.0545 |
| 3 | 95 | 2.5 | 71.81 | 0.0196 | 8.9 | 11.64 | 27.93 | 0.0409 | 11.1 | 14.90 | 53.08 | 0.0538 |
| 3 | 99 | 2.6 | 70.50 | 0.0197 | 8.9 | 11.52 | 27.82 | 0.0405 | 11.4 | 14.71 | 53.60 | 0.0541 |
| 4 | 2 | 3.8 | 72.98 | 0.0304 | 4.9 | 12.65 | 25.17 | 0.0196 | 10.7 | 14.85 | 48.61 | 0.0529 |
| 4 | 43 | 3.6 | 74.76 | 0.0297 | 4.4 | 11.09 | 26.33 | 0.0180 | 11.6 | 15.39 | 49.08 | 0.0584 |
| 4 | 54 | 3.6 | 75.40 | 0.0310 | 5.4 | 13.60 | 23.90 | 0.0213 | 11.5 | 15.03 | 49.77 | 0.0578 |
| 4 | 58 | 3.4 | 69.42 | 0.0260 | 4.5 | 13.31 | 25.32 | 0.0182 | 10.3 | 15.64 | 54.22 | 0.0538 |
| 4 | 62 | 3.6 | 74.69 | 0.0294 | 5.2 | 12.88 | 24.80 | 0.0209 | 11.4 | 15.30 | 50.06 | 0.0587 |
| 4 | 64 | 3.7 | 74.04 | 0.0305 | 5.6 | 13.50 | 24.99 | 0.0230 | 10.1 | 15.02 | 52.93 | 0.0542 |
| 4 | 72 | 3.6 | 72.86 | 0.0282 | 5.0 | 12.37 | 25.10 | 0.0203 | 10.9 | 15.92 | 51.08 | 0.0569 |
| 4 | 92 | 4.0 | 71.32 | 0.0315 | 5.3 | 12.56 | 23.98 | 0.0208 | 11.7 | 15.17 | 51.97 | 0.0642 |
| 4 | 95 | 4.1 | 67.09 | 0.0310 | 5.7 | 11.27 | 25.86 | 0.0241 | 11.6 | 14.62 | 51.14 | 0.0601 |
| 4 | 99 | 4.1 | 72.12 | 0.0328 | 5.3 | 12.15 | 24.55 | 0.0208 | 11.1 | 14.53 | 52.86 | 0.0570 |
| 5 | 2 | 3.9 | 77.71 | 0.0330 | 5.9 | 11.65 | 25.28 | 0.0232 | 9.7 | 14.22 | 57.15 | 0.0533 |
| 5 | 43 | 4.1 | 78.88 | 0.0352 | 5.1 | 11.39 | 26.30 | 0.0211 | 10.1 | 15.50 | 56.54 | 0.0562 |
| 5 | 54 | 3.8 | 78.77 | 0.0343 | 6.4 | 13.98 | 24.07 | 0.0254 | 11.3 | 15.28 | 55.66 | 0.0597 |

| | | B-747P | KC-10 | | | Throughput | | | Timeliness | | Factor Scores | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Des Pt | Rand Stream | Use Rate | Use Rate | Average Payload | MTM/D | Outsize Tons | Pax | Cargo Tons | Pct Ontime | Days Late | 1 | 2 | 3 | 4 |
| 0 | 3 | 4.9 | 1.2 | 42.80 | 0.0048 | 7590 | 56882 | 74317 | 84.02 | 0.69 | -0.66 | -0.10 | -1.81 | 0.75 |
| 0 | 13 | 4.9 | 1.1 | 43.77 | 0.0041 | 7613 | 56469 | 71036 | 84.51 | 0.67 | -0.92 | -0.62 | -1.55 | -0.59 |
| 0 | 22 | 4.9 | 1.3 | 41.37 | 0.0045 | 7583 | 56399 | 71011 | 84.47 | 0.67 | -0.91 | -0.68 | -1.22 | -0.64 |
| 0 | 31 | 4.9 | 1.4 | 42.20 | 0.0051 | 7590 | 57068 | 74308 | 84.43 | 0.67 | -0.63 | -0.23 | -1.79 | 0.58 |
| 0 | 41 | 4.8 | 1.4 | 41.38 | 0.0047 | 7552 | 56469 | 70978 | 84.47 | 0.67 | -0.87 | -0.77 | -1.27 | -0.69 |
| 0 | 54 | 4.8 | 1.7 | 41.87 | 0.0057 | 7593 | 56900 | 74267 | 84.42 | 0.68 | -0.54 | -0.17 | -1.79 | 0.69 |
| 0 | 64 | 4.9 | 1.6 | 41.47 | 0.0057 | 7616 | 56629 | 71053 | 84.38 | 0.68 | -0.75 | -0.60 | -1.30 | -0.64 |
| 0 | 72 | 4.8 | 1.5 | 42.28 | 0.0051 | 7579 | 57030 | 74284 | 84.40 | 0.68 | -0.70 | -0.07 | -1.66 | 0.68 |
| 0 | 83 | 5.0 | 1.1 | 41.34 | 0.0040 | 7593 | 56445 | 71006 | 84.48 | 0.67 | -0.82 | -0.55 | -1.44 | -0.62 |
| 0 | 96 | 4.9 | 1.1 | 42.43 | 0.0041 | 7576 | 56228 | 71018 | 84.51 | 0.67 | -0.73 | -0.51 | -1.72 | -0.45 |
| 1 | 2 | 5.3 | 2.2 | 41.78 | 0.0070 | 13887 | 61095 | 74887 | 78.83 | 0.84 | -1.13 | 0.95 | 1.19 | 0.24 |
| 1 | 43 | 5.2 | 2.1 | 42.12 | 0.0067 | 13473 | 60921 | 74475 | 79.00 | 0.84 | -1.12 | 0.82 | 1.13 | 0.08 |
| 1 | 54 | 5.4 | 2.1 | 41.95 | 0.0068 | 13532 | 61226 | 74534 | 79.90 | 0.82 | -0.99 | 0.82 | 0.80 | 0.08 |
| 1 | 58 | 5.2 | 2.1 | 41.89 | 0.0067 | 13618 | 60684 | 74646 | 78.92 | 0.85 | -1.12 | 0.86 | 1.17 | 0.15 |
| 1 | 62 | 5.2 | 2.1 | 41.60 | 0.0071 | 13922 | 61073 | 74928 | 78.87 | 0.85 | -1.05 | 0.96 | 1.14 | 0.24 |
| 1 | 64 | 5.4 | 2.1 | 41.63 | 0.0069 | 13989 | 61375 | 74987 | 78.83 | 0.84 | -1.09 | 1.00 | 1.22 | 0.25 |
| 1 | 72 | 5.3 | 2.3 | 41.73 | 0.0077 | 13471 | 61266 | 74499 | 79.02 | 0.84 | -1.12 | 0.79 | 1.16 | 0.18 |
| 1 | 92 | 5.2 | 2.2 | 40.84 | 0.0071 | 13850 | 61306 | 74866 | 78.86 | 0.85 | -1.10 | 0.86 | 1.29 | 0.24 |
| 1 | 95 | 5.4 | 2.2 | 41.72 | 0.0071 | 13612 | 61150 | 74626 | 79.43 | 0.83 | -0.96 | 0.91 | 0.90 | 0.17 |
| 1 | 99 | 5.1 | 2.1 | 41.61 | 0.0069 | 13348 | 60895 | 74335 | 79.73 | 0.81 | -1.06 | 0.74 | 0.82 | 0.03 |
| 2 | 2 | 4.8 | 0.9 | 42.99 | 0.0033 | 13180 | 54873 | 68666 | 79.52 | 0.80 | -1.11 | 1.16 | 0.28 | -1.25 |
| 2 | 43 | 5.0 | 1.5 | 41.43 | 0.0051 | 13883 | 55770 | 69367 | 79.30 | 0.82 | -0.97 | 1.27 | 0.51 | -1.00 |
| 2 | 54 | 5.0 | 1.3 | 39.98 | 0.0044 | 13252 | 55018 | 68751 | 78.86 | 0.84 | -1.00 | 1.11 | 0.87 | -1.13 |
| 2 | 58 | 4.9 | 1.0 | 43.02 | 0.0037 | 13862 | 55574 | 69374 | 79.66 | 0.80 | -1.06 | 1.36 | 0.12 | -1.03 |
| 2 | 62 | 4.7 | 1.0 | 42.44 | 0.0035 | 14044 | 55531 | 69577 | 79.52 | 0.80 | -0.95 | 1.37 | 0.18 | -1.06 |
| 2 | 64 | 4.8 | 1.2 | 39.69 | 0.0041 | 14041 | 55292 | 69532 | 79.47 | 0.81 | -0.97 | 1.20 | 0.56 | -1.08 |
| 2 | 72 | 4.6 | 1.1 | 42.33 | 0.0038 | 14024 | 55127 | 69538 | 79.22 | 0.82 | -1.09 | 1.36 | 0.44 | -1.01 |
| 2 | 92 | 4.8 | 1.0 | 40.27 | 0.0032 | 13749 | 55746 | 69251 | 79.78 | 0.79 | -0.95 | 1.25 | 0.34 | -1.06 |
| 2 | 95 | 4.7 | 1.3 | 42.31 | 0.0044 | 13562 | 54754 | 69068 | 79.15 | 0.83 | -1.13 | 1.15 | 0.65 | -1.24 |
| 2 | 99 | 5.0 | 1.3 | 41.02 | 0.0044 | 14039 | 55631 | 69529 | 78.92 | 0.84 | -0.99 | 1.24 | 0.62 | -0.96 |
| 3 | 2 | 5.3 | 1.9 | 41.44 | 0.0062 | 8403 | 60661 | 78168 | 80.42 | 0.78 | -0.96 | -0.20 | 0.03 | 1.54 |
| 3 | 43 | 5.5 | 2.0 | 41.76 | 0.0070 | 8516 | 61890 | 78315 | 80.22 | 0.78 | -1.00 | -0.14 | 0.14 | 1.58 |
| 3 | 54 | 5.2 | 2.0 | 41.89 | 0.0072 | 8459 | 61059 | 78273 | 79.87 | 0.79 | -1.11 | -0.24 | 0.22 | 1.53 |
| 3 | 58 | 5.2 | 1.9 | 41.83 | 0.0064 | 8401 | 61724 | 78206 | 80.56 | 0.78 | -0.98 | -0.27 | -0.02 | 1.53 |
| 3 | 62 | 5.5 | 2.0 | 41.59 | 0.0067 | 8460 | 60881 | 78240 | 80.50 | 0.78 | -1.03 | -0.33 | 0.23 | 1.40 |
| 3 | 64 | 5.2 | 1.7 | 40.85 | 0.0060 | 8456 | 61066 | 78258 | 80.32 | 0.78 | -1.12 | -0.39 | 0.25 | 1.43 |
| 3 | 72 | 5.1 | 1.9 | 39.89 | 0.0064 | 8392 | 60635 | 78204 | 80.14 | 0.79 | -1.06 | -0.58 | 0.44 | 1.34 |
| 3 | 92 | 5.3 | 1.8 | 40.93 | 0.0064 | 8457 | 61394 | 78246 | 80.66 | 0.77 | -1.07 | -0.35 | 0.15 | 1.46 |
| 3 | 95 | 5.2 | 1.9 | 40.93 | 0.0062 | 8492 | 60542 | 78295 | 80.08 | 0.79 | -1.07 | -0.52 | 0.35 | 1.33 |
| 3 | 99 | 5.3 | 1.9 | 41.53 | 0.0068 | 8483 | 61195 | 78278 | 79.96 | 0.79 | -1.08 | -0.34 | 0.37 | 1.44 |
| 4 | 2 | 7.8 | 3.8 | 39.26 | 0.0105 | 14157 | 78666 | 69877 | 80.05 | 0.81 | 1.06 | 0.89 | 0.29 | -1.07 |
| 4 | 43 | 7.3 | 2.6 | 41.36 | 0.0074 | 13550 | 74438 | 68437 | 80.06 | 0.82 | 1.07 | 1.41 | -0.71 | -0.82 |
| 4 | 54 | 6.0 | 4.4 | 39.29 | 0.0120 | 13838 | 61231 | 68983 | 80.52 | 0.78 | 1.59 | 1.32 | -1.09 | -0.93 |
| 4 | 58 | 6.3 | 4.8 | 40.93 | 0.0144 | 12905 | 62904 | 64188 | 79.96 | 0.81 | 1.32 | 0.65 | -0.64 | -2.27 |
| 4 | 62 | 7.4 | 2.9 | 42.26 | 0.0081 | 12779 | 74905 | 68975 | 79.94 | 0.82 | 1.26 | 1.22 | -0.89 | -0.73 |
| 4 | 64 | 7.7 | 3.6 | 39.79 | 0.0111 | 12887 | 79054 | 70994 | 80.06 | 0.81 | 1.02 | 0.18 | 0.17 | -0.69 |
| 4 | 72 | 7.7 | 3.2 | 40.35 | 0.0088 | 12603 | 79248 | 66426 | 80.14 | 0.82 | 1.33 | 0.85 | -0.65 | -1.33 |
| 4 | 92 | 8.0 | 2.7 | 38.81 | 0.0072 | 15489 | 81395 | 70313 | 79.87 | 0.82 | 1.61 | 1.71 | -0.65 | -0.09 |
| 4 | 95 | 7.6 | 3.7 | 40.73 | 0.0111 | 15968 | 87918 | 74000 | 80.17 | 0.82 | 0.80 | 1.56 | 0.36 | 0.61 |
| 4 | 99 | 7.1 | 2.6 | 40.69 | 0.0073 | 14228 | 73737 | 71543 | 80.49 | 0.78 | 0.95 | 1.06 | -0.33 | -0.42 |
| 5 | 2 | 9.0 | 3.7 | 39.80 | 0.0105 | 7593 | 86859 | 76351 | 79.90 | 0.82 | 0.36 | -1.16 | 1.28 | 0.72 |
| 5 | 43 | 7.7 | 2.6 | 41.48 | 0.0078 | 7320 | 82534 | 75201 | 79.77 | 0.83 | 0.63 | -0.84 | 0.30 | 0.52 |
| 5 | 54 | 6.4 | 4.5 | 39.82 | 0.0129 | 8201 | 64935 | 76278 | 79.79 | 0.82 | 1.30 | -0.12 | -0.49 | 1.00 |

| | | C-5A | | | C-141B | | | | C-17 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Des Pt | Rand Stream | Use Rate | Average Payload | MTM/D | Use Rate | G-Cycle Time | Average Payload | MTM/D | Use Rate | G-Cycle Time | Average Payload | MTM/D |
| 5 | 58 | 3.6 | 75.23 | 0.0293 | 5.4 | 13.37 | 25.43 | 0.0216 | 8.4 | 15.59 | 61.38 | 0.0496 |
| 5 | 62 | 3.7 | 79.06 | 0.0329 | 6.6 | 13.59 | 24.30 | 0.0259 | 10.6 | 15.62 | 58.39 | 0.0604 |
| 5 | 64 | 3.7 | 79.30 | 0.0332 | 7.0 | 13.55 | 24.81 | 0.0279 | 10.0 | 15.17 | 58.77 | 0.0550 |
| 5 | 72 | 3.7 | 77.89 | 0.0315 | 5.7 | 12.39 | 24.49 | 0.0233 | 10.9 | 15.74 | 58.19 | 0.0608 |
| 5 | 92 | 4.2 | 75.09 | 0.0349 | 6.2 | 13.43 | 24.24 | 0.0246 | 11.3 | 15.76 | 59.05 | 0.0643 |
| 5 | 95 | 4.4 | 72.97 | 0.0368 | 6.1 | 11.49 | 26.03 | 0.0256 | 10.6 | 15.01 | 58.67 | 0.0607 |
| 5 | 99 | 4.2 | 76.98 | 0.0361 | 6.1 | 12.33 | 24.85 | 0.0238 | 10.2 | 15.81 | 60.54 | 0.0571 |
| 6 | 2 | 3.8 | 76.84 | 0.0324 | 5.1 | 11.80 | 24.56 | 0.0202 | 8.7 | 15.01 | 57.24 | 0.0468 |
| 6 | 43 | 3.7 | 78.20 | 0.0322 | 4.5 | 11.10 | 26.76 | 0.0190 | 9.3 | 15.67 | 57.25 | 0.0520 |
| 6 | 54 | 3.6 | 78.09 | 0.0325 | 5.9 | 14.06 | 23.85 | 0.0231 | 10.9 | 15.52 | 55.74 | 0.0554 |
| 6 | 58 | 3.2 | 74.19 | 0.0268 | 4.8 | 13.00 | 25.14 | 0.0196 | 8.8 | 15.69 | 59.30 | 0.0479 |
| 6 | 62 | 3.4 | 77.70 | 0.0301 | 5.8 | 13.09 | 24.22 | 0.0232 | 9.8 | 15.57 | 59.50 | 0.0570 |
| 6 | 64 | 3.5 | 78.19 | 0.0308 | 6.3 | 13.79 | 24.80 | 0.0256 | 9.0 | 15.12 | 60.38 | 0.0500 |
| 6 | 72 | 3.4 | 77.49 | 0.0284 | 5.1 | 12.99 | 25.11 | 0.0208 | 10.4 | 15.52 | 58.53 | 0.0587 |
| 6 | 92 | 3.9 | 75.52 | 0.0323 | 5.9 | 12.87 | 23.77 | 0.0227 | 11.2 | 15.78 | 61.74 | 0.0654 |
| 6 | 95 | 4.1 | 71.59 | 0.0334 | 5.9 | 11.42 | 25.79 | 0.0248 | 10.1 | 15.61 | 58.98 | 0.0543 |
| 6 | 99 | 4.0 | 76.90 | 0.0335 | 5.4 | 12.19 | 24.96 | 0.0219 | 9.5 | 15.71 | 60.97 | 0.0536 |
| 7 | 2 | 4.1 | 73.08 | 0.0332 | 5.4 | 12.19 | 25.47 | 0.0217 | 11.3 | 14.32 | 49.39 | 0.0581 |
| 7 | 43 | 3.9 | 76.32 | 0.0324 | 4.7 | 11.24 | 27.09 | 0.0200 | 11.7 | 15.27 | 48.27 | 0.0597 |
| 7 | 54 | 3.7 | 76.96 | 0.0326 | 6.1 | 13.65 | 24.29 | 0.0241 | 11.6 | 15.58 | 49.84 | 0.0595 |
| 7 | 58 | 3.6 | 69.67 | 0.0279 | 5.1 | 13.25 | 25.54 | 0.0204 | 10.4 | 15.74 | 55.01 | 0.0560 |
| 7 | 62 | 3.8 | 75.33 | 0.0320 | 5.7 | 13.09 | 24.73 | 0.0229 | 11.7 | 15.13 | 49.91 | 0.0629 |
| 7 | 64 | 3.7 | 76.46 | 0.0315 | 6.3 | 13.22 | 25.17 | 0.0254 | 11.3 | 14.49 | 52.55 | 0.0610 |
| 7 | 72 | 3.8 | 73.59 | 0.0307 | 5.2 | 12.90 | 25.50 | 0.0217 | 11.3 | 15.61 | 49.15 | 0.0580 |
| 7 | 92 | 4.3 | 70.86 | 0.0335 | 5.7 | 12.90 | 24.64 | 0.0228 | 11.5 | 14.64 | 53.76 | 0.0645 |
| 7 | 95 | 4.5 | 68.32 | 0.0354 | 5.8 | 11.38 | 26.34 | 0.0251 | 11.6 | 14.88 | 50.29 | 0.0614 |
| 7 | 99 | 4.3 | 73.82 | 0.0351 | 5.6 | 12.43 | 25.21 | 0.0222 | 11.6 | 15.33 | 54.22 | 0.0626 |
| 8 | 2 | 2.4 | 69.77 | 0.0177 | 8.4 | 11.23 | 27.34 | 0.0375 | 11.0 | 14.35 | 55.49 | 0.0576 |
| 8 | 7 | 2.5 | 70.64 | 0.0192 | 8.5 | 11.35 | 27.42 | 0.0380 | 10.2 | 14.84 | 55.35 | 0.0507 |
| 8 | 11 | 2.4 | 70.21 | 0.0177 | 8.5 | 11.43 | 27.54 | 0.0382 | 10.6 | 14.61 | 55.06 | 0.0545 |
| 8 | 12 | 2.3 | 71.58 | 0.0179 | 8.4 | 11.62 | 27.48 | 0.0380 | 10.3 | 14.83 | 53.32 | 0.0507 |
| 8 | 30 | 2.3 | 70.69 | 0.0175 | 8.1 | 11.33 | 27.75 | 0.0370 | 10.3 | 14.95 | 54.19 | 0.0485 |
| 8 | 48 | 2.4 | 70.07 | 0.0181 | 8.0 | 11.47 | 27.46 | 0.0359 | 9.9 | 14.78 | 54.52 | 0.0483 |
| 8 | 61 | 2.4 | 71.22 | 0.0184 | 8.6 | 11.35 | 27.52 | 0.0388 | 10.5 | 14.70 | 54.14 | 0.0522 |
| 8 | 74 | 2.3 | 69.82 | 0.0172 | 8.5 | 11.57 | 27.66 | 0.0383 | 11.1 | 14.34 | 55.57 | 0.0577 |
| 8 | 80 | 2.4 | 70.30 | 0.0179 | 8.1 | 11.55 | 27.56 | 0.0366 | 10.1 | 14.68 | 53.45 | 0.0477 |
| 8 | 89 | 2.3 | 69.93 | 0.0174 | 8.1 | 11.33 | 27.76 | 0.0366 | 10.1 | 14.89 | 54.25 | 0.0476 |
| 9 | 25 | 3.9 | 74.19 | 0.0316 | 4.7 | 12.90 | 26.01 | 0.0199 | 11.0 | 15.50 | 62.71 | 0.0694 |
| 9 | 31 | 3.9 | 76.63 | 0.0329 | 5.1 | 13.18 | 25.44 | 0.0207 | 10.1 | 15.13 | 56.51 | 0.0510 |
| 9 | 40 | 3.5 | 75.93 | 0.0296 | 4.7 | 11.71 | 25.40 | 0.0191 | 9.7 | 14.97 | 57.77 | 0.0472 |
| 9 | 45 | 4.1 | 76.80 | 0.0339 | 5.8 | 12.19 | 24.05 | 0.0226 | 9.8 | 15.55 | 56.54 | 0.0500 |
| 9 | 51 | 3.0 | 76.90 | 0.0260 | 7.2 | 14.37 | 23.59 | 0.0279 | 9.9 | 15.90 | 58.53 | 0.0506 |
| 9 | 57 | 4.3 | 72.94 | 0.0344 | 5.5 | 12.87 | 24.65 | 0.0222 | 9.7 | 15.93 | 60.56 | 0.0521 |
| 9 | 67 | 3.5 | 74.98 | 0.0294 | 5.3 | 13.00 | 24.89 | 0.0214 | 11.5 | 15.45 | 61.39 | 0.0686 |
| 9 | 68 | 3.7 | 73.36 | 0.0295 | 8.1 | 12.07 | 23.69 | 0.0308 | 8.9 | 15.04 | 56.18 | 0.0509 |
| 9 | 70 | 4.9 | 73.75 | 0.0389 | 4.9 | 13.42 | 25.20 | 0.0193 | 8.0 | 14.59 | 57.16 | 0.0413 |
| 9 | 73 | 3.4 | 75.33 | 0.0286 | 5.6 | 13.09 | 25.02 | 0.0230 | 10.0 | 15.76 | 60.47 | 0.0590 |
| | Mean | 3.17 | 71.84 | 0.0253 | 6.9 | 12.07 | 26.24 | 0.0298 | 10.8 | 14.87 | 53.45 | 0.0543 |
| | Std Dev | 0.71 | 4.11 | 0.0069 | 1.5 | 0.86 | 1.37 | 0.0078 | 0.9 | 0.58 | 4.46 | 0.0052 |
| | Coef Var | 22.4% | 5.7% | 27.2% | 21.3% | 7.1% | 5.2% | 26.1% | 8.0% | 3.9% | 8.4% | 9.6% |

| | | B-747P | KC-10 | | | Throughput | | | Timeliness | | Factor Scores | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Des Pt | Rand Stream | Use Rate | Use Rate | Average Payload | MTM/D | Outsize Tons | Pax | Cargo Tons | Pct Ontime | Days Late | 1 | 2 | 3 | 4 |
| 5 | 58 | 6.5 | 5.4 | 40.71 | 0.0161 | 6701 | 67516 | 69974 | 79.94 | 0.81 | 0.75 | -1.88 | 0.45 | -1.26 |
| 5 | 62 | 8.1 | 3.6 | 41.25 | 0.0102 | 6959 | 81887 | 77026 | 79.89 | 0.82 | 1.15 | -0.77 | -0.34 | 1.32 |
| 5 | 64 | 8.2 | 4.5 | 40.33 | 0.0147 | 6751 | 85564 | 78863 | 79.82 | 0.82 | 0.77 | -1.43 | 0.70 | 1.47 |
| 5 | 72 | 8.7 | 4.0 | 40.75 | 0.0118 | 7602 | 86736 | 74216 | 79.75 | 0.84 | 1.32 | -0.43 | -0.20 | 0.93 |
| 5 | 92 | 8.0 | 3.7 | 38.63 | 0.0100 | 8211 | 79162 | 77515 | 79.94 | 0.81 | 1.52 | -0.15 | -0.47 | 1.64 |
| 5 | 95 | 6.7 | 5.2 | 41.30 | 0.0161 | 8558 | 71889 | 81318 | 79.78 | 0.84 | 0.62 | -0.50 | 0.71 | 2.13 |
| 5 | 99 | 7.8 | 3.3 | 40.95 | 0.0114 | 7787 | 82989 | 78460 | 79.84 | 0.82 | 0.89 | -1.08 | 0.31 | 1.31 |
| 6 | 2 | 8.0 | 3.5 | 39.87 | 0.0100 | 6951 | 78389 | 70111 | 79.83 | 0.83 | 0.40 | -1.64 | 1.18 | -1.34 |
| 6 | 43 | 7.1 | 2.3 | 41.89 | 0.0067 | 6640 | 74952 | 69116 | 79.76 | 0.84 | 0.40 | -1.20 | 0.23 | -1.14 |
| 6 | 54 | 5.7 | 4.5 | 39.83 | 0.0126 | 7614 | 59234 | 71594 | 79.96 | 0.82 | 1.28 | -0.31 | -0.65 | -0.38 |
| 6 | 58 | 6.2 | 5.2 | 40.49 | 0.0149 | 6584 | 62419 | 65039 | 79.81 | 0.83 | 0.78 | -1.47 | 0.21 | -2.38 |
| 6 | 62 | 7.2 | 3.2 | 41.94 | 0.0088 | 6337 | 73643 | 70483 | 79.82 | 0.83 | 0.93 | -1.01 | -0.45 | -0.44 |
| 6 | 64 | 7.4 | 4.2 | 39.63 | 0.0126 | 6239 | 77129 | 72469 | 79.77 | 0.84 | 0.58 | -1.90 | 0.84 | -0.41 |
| 6 | 72 | 7.5 | 3.6 | 39.56 | 0.0098 | 6714 | 77715 | 68217 | 79.75 | 0.84 | 1.23 | -0.58 | -0.45 | -0.60 |
| 6 | 92 | 7.6 | 3.2 | 38.40 | 0.0081 | 7837 | 74405 | 73834 | 79.81 | 0.83 | 1.51 | -0.22 | -0.76 | 0.95 |
| 6 | 95 | 7.5 | 3.7 | 40.75 | 0.0107 | 7885 | 86482 | 74693 | 79.76 | 0.84 | 0.46 | -0.92 | 0.86 | 0.48 |
| 6 | 99 | 7.2 | 2.7 | 39.79 | 0.0073 | 7079 | 75999 | 72124 | 79.95 | 0.82 | 0.72 | -1.37 | 0.23 | -0.40 |
| 7 | 2 | 8.0 | 3.9 | 39.93 | 0.0113 | 15506 | 80050 | 75883 | 79.44 | 0.86 | 0.89 | 1.25 | 0.79 | 0.62 |
| 7 | 43 | 7.7 | 2.9 | 42.48 | 0.0088 | 14566 | 81331 | 73723 | 79.42 | 0.86 | 0.94 | 1.43 | -0.09 | 0.41 |
| 7 | 54 | 6.3 | 4.5 | 40.60 | 0.0132 | 14800 | 64657 | 73521 | 79.73 | 0.84 | 1.51 | 1.23 | -0.68 | 0.19 |
| 7 | 58 | 6.5 | 4.9 | 41.06 | 0.0150 | 13449 | 66454 | 68460 | 79.40 | 0.86 | 1.20 | 0.55 | -0.10 | -1.18 |
| 7 | 62 | 8.2 | 3.2 | 41.95 | 0.0093 | 13995 | 80975 | 73999 | 79.38 | 0.86 | 1.36 | 1.41 | -0.41 | 0.66 |
| 7 | 64 | 8.2 | 4.2 | 40.11 | 0.0137 | 13528 | 84709 | 77141 | 79.43 | 0.86 | 1.08 | 0.71 | 0.46 | 1.38 |
| 7 | 72 | 8.6 | 3.8 | 40.73 | 0.0110 | 13195 | 85270 | 70308 | 79.44 | 0.86 | 1.37 | 1.07 | -0.03 | -0.33 |
| 7 | 92 | 7.2 | 4.0 | 38.80 | 0.0107 | 15540 | 70746 | 75014 | 79.36 | 0.86 | 1.31 | 1.42 | 0.09 | 0.81 |
| 7 | 95 | 7.2 | 4.4 | 41.26 | 0.0132 | 16539 | 78607 | 78846 | 79.53 | 0.85 | 0.80 | 1.55 | 0.68 | 1.50 |
| 7 | 99 | 6.5 | 3.3 | 40.51 | 0.0102 | 14810 | 74581 | 77247 | 79.70 | 0.84 | 1.23 | 1.11 | -0.25 | 1.15 |
| 8 | 2 | 4.9 | 1.7 | 41.29 | 0.0059 | 7602 | 56891 | 74364 | 83.90 | 0.64 | -0.62 | -0.26 | -1.67 | 0.68 |
| 8 | 7 | 4.7 | 1.4 | 41.97 | 0.0050 | 7545 | 56778 | 73859 | 82.49 | 0.64 | -0.96 | -0.90 | -0.94 | 0.00 |
| 8 | 11 | 4.8 | 1.3 | 41.03 | 0.0044 | 7635 | 55366 | 73389 | 84.05 | 0.64 | -0.75 | -0.55 | -1.58 | 0.19 |
| 8 | 12 | 4.7 | 1.4 | 41.90 | 0.0052 | 7545 | 55051 | 72677 | 83.75 | 0.64 | -0.82 | -0.73 | -1.43 | -0.28 |
| 8 | 30 | 4.8 | 1.1 | 40.90 | 0.0043 | 7574 | 55470 | 70414 | 83.86 | 0.65 | -0.87 | -0.82 | -1.29 | -0.82 |
| 8 | 48 | 4.5 | 1.4 | 41.24 | 0.0051 | 7615 | 55693 | 69841 | 84.14 | 0.64 | -0.82 | -0.91 | -1.32 | -1.07 |
| 8 | 61 | 4.8 | 1.4 | 41.87 | 0.0049 | 7610 | 56781 | 74353 | 83.81 | 0.65 | -0.89 | -0.70 | -1.32 | 0.24 |
| 8 | 74 | 4.8 | 1.2 | 42.08 | 0.0049 | 7628 | 56287 | 74340 | 83.69 | 0.65 | -0.72 | -0.21 | -1.75 | 0.69 |
| 8 | 80 | 4.7 | 1.5 | 42.59 | 0.0054 | 7587 | 55494 | 70333 | 83.99 | 0.64 | -0.90 | -0.77 | -1.33 | -0.95 |
| 8 | 89 | 4.8 | 1.3 | 41.96 | 0.0044 | 7558 | 55116 | 69792 | 83.96 | 0.64 | -0.93 | -0.85 | -1.34 | -1.05 |
| 9 | 25 | 7.7 | 3.0 | 40.38 | 0.0085 | 7919 | 84558 | 74466 | 78.50 | 1.08 | 1.17 | -0.17 | 0.59 | 1.35 |
| 9 | 31 | 7.1 | 3.9 | 39.08 | 0.0107 | 7846 | 72803 | 72952 | 80.18 | 0.79 | 0.86 | -0.83 | 0.27 | -0.44 |
| 9 | 40 | 7.1 | 4.0 | 39.40 | 0.0108 | 7040 | 71783 | 68547 | 78.37 | 1.10 | 0.09 | -1.31 | 2.43 | -1.42 |
| 9 | 45 | 7.1 | 4.0 | 40.37 | 0.0118 | 7795 | 79525 | 74406 | 78.95 | 1.03 | 0.44 | -1.24 | 1.94 | -0.10 |
| 9 | 51 | 7.3 | 3.6 | 39.46 | 0.0109 | 6942 | 72569 | 69897 | 79.51 | 0.90 | 0.72 | -1.36 | 0.41 | -0.80 |
| 9 | 57 | 7.3 | 3.5 | 39.61 | 0.0094 | 7177 | 74080 | 71541 | 79.24 | 0.90 | 0.78 | -1.23 | 0.87 | -0.60 |
| 9 | 67 | 6.8 | 3.8 | 38.89 | 0.0101 | 7482 | 66026 | 70187 | 77.70 | 1.08 | 1.25 | 0.11 | 0.35 | 0.54 |
| 9 | 68 | 8.3 | 2.9 | 39.18 | 0.0081 | 7987 | 94954 | 72528 | 78.82 | 1.05 | -0.23 | -1.66 | 2.78 | -0.07 |
| 9 | 70 | 7.7 | 2.6 | 40.58 | 0.0070 | 7851 | 76784 | 71429 | 79.38 | 0.95 | 0.02 | -1.90 | 2.47 | -1.78 |
| 9 | 73 | 7.0 | 3.0 | 40.67 | 0.0080 | 6864 | 71594 | 69911 | 79.23 | 0.94 | 0.82 | -0.87 | 0.08 | -0.42 |
| | Mean | 6.2 | 2.6 | 40.98 | 0.0081 | 10154 | 67168 | 72952 | 80.52 | 0.81 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Std Dev | 1.3 | 1.2 | 1.11 | 0.0033 | 3207 | 10855 | 3497 | 1.87 | 0.10 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Coef Var | 21.2% | 46% | 2.7% | 40.4% | 31.6% | 16.2% | 4.8% | 2.3% | 12% | | | | |

## Appendix F: Large Scenario Perturbation Run Data

The 29 variables used in the analysis of the large scenario perturbation runs are presented in this appendix. Though the 31 variables used in the random seed runs were desired for this section also, *C-17 ground cycle times* did not consistently output from AFM and had to be discarded. Also, *C-141B MTM/D per aircraft* was uniquely independent of all other variables and was removed.

Each row of data in this appendix represents the output from one run of AFM with the indicated random stream and a perturbed file 63 corresponding to the design point characteristics. At the bottom of each column of data are the mean, standard deviation, and coefficient of variation for the respective variables. As compared to relatively low coefficients of variation from random seed effects (See Appendix C), most of the variables seemed to be unaffected by the file63 perturbations. Note that *total cargo tons throughput* was again relatively unaffected by the perturbation schemes, as in the small scenario (See Appendix E). Also note, however, that *percent of shipments delivered ontime* was significantly affected by the perturbation schemes in the large scenario, but not in the small scenario.

The eight factor scores listed in this appendix were computed using the SAS factor analysis procedure, PROC FACTOR, with a varimax rotation. The number of factors selected by the SAS, using Kaiser's criterion, was 8, which was satisfactory. Loadings matrix interpretation and plots of these factors scores are provided in Chapter IV.

| | | Throughput | | | C-5A | | | | C-141B | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Des Pt | Rand Stream | Outsize Tons | Pax | Cargo Tons | Use Rate | G-Cycle Time | Average Payload | MTM/D | Use Rate | G-Cycle Time | Average Payload | MTM/D |
| 0 | 3 | 13191 | 165669 | 120217 | 10.9 | 42.37 | 61.30 | 0.1219 | 12.3 | 34.17 | 20.56 | 0.0422 |
| 0 | 13 | 12720 | 168513 | 120211 | 11.0 | 42.61 | 60.39 | 0.1207 | 12.5 | 33.12 | 20.72 | 0.0428 |
| 0 | 22 | 12604 | 171992 | 119632 | 10.9 | 42.37 | 59.24 | 0.1181 | 12.4 | 32.93 | 21.26 | 0.0432 |
| 0 | 31 | 12606 | 166008 | 118747 | 10.9 | 42.58 | 59.05 | 0.1164 | 12.3 | 34.01 | 21.06 | 0.0431 |
| 0 | 41 | 12812 | 167922 | 119001 | 11.0 | 42.17 | 58.97 | 0.1179 | 12.5 | 33.72 | 20.67 | 0.0423 |
| 0 | 54 | 12918 | 174773 | 121003 | 10.9 | 42.30 | 61.79 | 0.1225 | 12.4 | 33.17 | 20.57 | 0.0422 |
| 0 | 64 | 13112 | 176542 | 120273 | 10.9 | 42.18 | 61.43 | 0.1216 | 12.5 | 32.94 | 20.56 | 0.0429 |
| 0 | 72 | 12579 | 169230 | 118809 | 10.9 | 42.62 | 58.81 | 0.1162 | 12.3 | 34.11 | 20.80 | 0.0426 |
| 0 | 83 | 12409 | 169628 | 120194 | 11.0 | 42.40 | 60.01 | 0.1204 | 12.4 | 33.47 | 20.51 | 0.0422 |
| 0 | 96 | 12732 | 172946 | 120186 | 11.0 | 42.33 | 60.69 | 0.1219 | 12.4 | 33.70 | 20.62 | 0.0420 |
| 1 | 2 | 26782 | 171908 | 119407 | 10.9 | 42.68 | 60.56 | 0.1179 | 12.4 | 32.98 | 20.91 | 0.0435 |
| 1 | 3 | 27023 | 170321 | 119517 | 10.9 | 42.39 | 61.20 | 0.1208 | 12.4 | 33.84 | 20.83 | 0.0432 |
| 1 | 7 | 26104 | 173248 | 118075 | 10.9 | 42.21 | 61.01 | 0.1191 | 12.3 | 33.85 | 20.91 | 0.0430 |
| 1 | 12 | 26634 | 170614 | 118723 | 10.9 | 42.50 | 61.17 | 0.1191 | 12.3 | 33.76 | 21.01 | 0.0430 |
| 1 | 30 | 26687 | 169917 | 119486 | 10.9 | 42.73 | 61.23 | 0.1207 | 12.2 | 34.49 | 20.94 | 0.0430 |
| 1 | 35 | 26231 | 174860 | 118485 | 10.9 | 42.58 | 60.75 | 0.1181 | 12.4 | 33.79 | 20.87 | 0.0428 |
| 1 | 39 | 26197 | 169946 | 119263 | 10.9 | 42.57 | 60.29 | 0.1184 | 12.3 | 33.89 | 21.00 | 0.0425 |
| 1 | 49 | 26820 | 169964 | 119169 | 10.9 | 42.68 | 60.90 | 0.1188 | 12.4 | 33.88 | 20.94 | 0.0435 |
| 1 | 71 | 26416 | 171161 | 119414 | 10.9 | 42.32 | 60.92 | 0.1196 | 12.3 | 33.51 | 21.02 | 0.0428 |
| 1 | 90 | 26650 | 177827 | 119190 | 10.9 | 42.69 | 61.08 | 0.1192 | 12.4 | 33.68 | 20.66 | 0.0426 |
| 2 | 2 | 24838 | 172537 | 117274 | 10.8 | 42.63 | 61.05 | 0.1184 | 12.2 | 33.03 | 21.03 | 0.0416 |
| 2 | 3 | 24911 | 173267 | 118035 | 10.8 | 42.55 | 61.18 | 0.1193 | 12.2 | 34.05 | 20.82 | 0.0414 |
| 2 | 7 | 24980 | 172486 | 115460 | 10.7 | 43.42 | 60.37 | 0.1152 | 12.3 | 34.38 | 20.42 | 0.0413 |
| 2 | 12 | 24785 | 172602 | 116595 | 10.7 | 43.36 | 60.59 | 0.1159 | 12.3 | 32.87 | 20.59 | 0.0416 |
| 2 | 30 | 26959 | 168109 | 118204 | 10.8 | 41.73 | 60.67 | 0.1179 | 12.3 | 33.84 | 20.68 | 0.0423 |
| 2 | 35 | 24754 | 171150 | 116926 | 10.8 | 42.65 | 58.84 | 0.1135 | 12.2 | 34.27 | 20.77 | 0.0419 |
| 2 | 39 | 25497 | 172949 | 117443 | 10.8 | 42.60 | 60.06 | 0.1171 | 12.3 | 33.24 | 20.72 | 0.0419 |
| 2 | 49 | 26868 | 169336 | 117928 | 10.7 | 42.78 | 60.65 | 0.1171 | 12.2 | 33.78 | 20.87 | 0.0417 |
| 2 | 71 | 25305 | 173551 | 116841 | 10.8 | 42.52 | 60.10 | 0.1165 | 12.4 | 33.20 | 20.94 | 0.0423 |
| 2 | 90 | 25250 | 169562 | 117971 | 10.7 | 42.35 | 60.53 | 0.1177 | 12.3 | 34.04 | 20.38 | 0.0419 |
| 3 | 2 | 13109 | 168321 | 120310 | 10.8 | 42.32 | 62.10 | 0.1201 | 12.2 | 33.64 | 21.09 | 0.0424 |
| 3 | 3 | 12996 | 167503 | 118013 | 10.6 | 43.35 | 61.50 | 0.1160 | 12.2 | 34.96 | 21.13 | 0.0419 |
| 3 | 7 | 12913 | 172112 | 118505 | 10.8 | 43.33 | 61.57 | 0.1185 | 12.0 | 35.04 | 21.43 | 0.0420 |
| 3 | 12 | 12854 | 173657 | 118497 | 10.8 | 43.22 | 61.03 | 0.1171 | 12.2 | 32.71 | 21.23 | 0.0424 |
| 3 | 30 | 13365 | 169927 | 119414 | 10.8 | 41.91 | 61.52 | 0.1193 | 12.3 | 33.31 | 21.03 | 0.0417 |
| 3 | 35 | 12854 | 175810 | 119050 | 10.7 | 43.53 | 61.28 | 0.1161 | 12.0 | 35.24 | 21.35 | 0.0417 |
| 3 | 39 | 14788 | 170762 | 120402 | 10.9 | 41.87 | 60.76 | 0.1182 | 12.4 | 32.54 | 21.74 | 0.0449 |
| 3 | 49 | 13342 | 165116 | 118933 | 10.9 | 41.96 | 61.02 | 0.1186 | 12.1 | 33.87 | 20.93 | 0.0415 |
| 3 | 71 | 12946 | 169919 | 118057 | 10.8 | 42.68 | 61.25 | 0.1178 | 12.3 | 33.29 | 21.02 | 0.0421 |
| 3 | 90 | 12973 | 166988 | 119199 | 10.7 | 42.99 | 61.92 | 0.1178 | 12.0 | 34.51 | 21.07 | 0.0417 |
| 4 | 2 | 19853 | 176640 | 110118 | 10.6 | 45.11 | 59.50 | 0.1160 | 12.5 | 35.30 | 23.05 | 0.0430 |
| 4 | 3 | 27254 | 177833 | 115107 | 10.8 | 45.01 | 60.65 | 0.1100 | 12.3 | 34.92 | 22.91 | 0.0400 |
| 4 | 7 | 27553 | 161912 | 111526 | 10.7 | 44.34 | 58.99 | 0.1195 | 12.8 | 28.72 | 23.76 | 0.0380 |
| 4 | 12 | 23948 | 161168 | 110666 | 10.6 | 45.90 | 61.48 | 0.1188 | 12.3 | 39.43 | 22.27 | 0.0466 |
| 4 | 30 | 24498 | 172837 | 111136 | 10.6 | 44.79 | 58.94 | 0.1171 | 12.4 | 33.44 | 23.06 | 0.0409 |
| 4 | 35 | 24964 | 179379 | 111228 | 10.7 | 45.16 | 61.55 | 0.1178 | 12.3 | 35.15 | 19.59 | 0.0398 |
| 4 | 39 | 25008 | 177077 | 111619 | 10.8 | 45.05 | 58.89 | 0.1137 | 12.3 | 34.63 | 19.81 | 0.0384 |
| 4 | 49 | 23294 | 172025 | 113000 | 10.9 | 43.32 | 60.33 | 0.1189 | 12.1 | 37.86 | 21.83 | 0.0420 |
| 4 | 71 | 26157 | 172506 | 111293 | 10.9 | 42.84 | 59.89 | 0.1156 | 12.6 | 35.03 | 18.30 | 0.0365 |
| 4 | 90 | 22507 | 176530 | 111222 | 10.8 | 45.94 | 60.09 | 0.1133 | 12.6 | 34.52 | 21.29 | 0.0403 |
| 5 | 2 | 12725 | 170584 | 110039 | 10.5 | 47.09 | 62.27 | 0.1222 | 12.7 | 33.96 | 23.10 | 0.0430 |
| 5 | 3 | 14911 | 179209 | 116739 | 10.7 | 44.90 | 62.16 | 0.1126 | 12.3 | 34.25 | 22.89 | 0.0403 |
| 5 | 7 | 15659 | 165517 | 118363 | 10.7 | 44.29 | 62.00 | 0.1258 | 13.2 | 24.59 | 24.52 | 0.0387 |

| | | C-17 | | | KC-10 | | | | B-747 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Des Pt | Rand Stream | Use Rate | Average Payload | MTM/D | Use Rate | G-Cycle Time | Average Payload | MTM/D | Use Rate | G-Cycle Time | Average Payload | MTM/D |
| 0 | 3 | 14.8 | 43.43 | 0.1135 | 12.5 | 29.79 | 32.63 | 0.0854 | 9.4 | 35.95 | 64.72 | 0.1235 |
| 0 | 13 | 14.6 | 42.10 | 0.1099 | 12.7 | 29.08 | 35.27 | 0.0936 | 9.4 | 36.46 | 65.47 | 0.1245 |
| 0 | 22 | 14.6 | 42.99 | 0.1131 | 12.6 | 29.11 | 33.14 | 0.0881 | 9.4 | 36.38 | 64.63 | 0.1241 |
| 0 | 31 | 14.6 | 43.48 | 0.1144 | 12.7 | 28.95 | 32.11 | 0.0862 | 9.4 | 35.84 | 65.47 | 0.1256 |
| 0 | 41 | 14.8 | 43.54 | 0.1137 | 12.6 | 29.69 | 32.88 | 0.0877 | 9.3 | 36.81 | 64.51 | 0.1216 |
| 0 | 54 | 14.7 | 43.65 | 0.1146 | 12.7 | 28.96 | 32.58 | 0.0865 | 9.4 | 36.75 | 65.27 | 0.1248 |
| 0 | 64 | 14.7 | 42.17 | 0.1106 | 12.6 | 29.69 | 33.41 | 0.0890 | 9.4 | 36.01 | 65.50 | 0.1249 |
| 0 | 72 | 14.6 | 43.48 | 0.1136 | 12.6 | 29.33 | 33.09 | 0.0887 | 9.4 | 36.88 | 64.90 | 0.1232 |
| 0 | 83 | 14.7 | 42.64 | 0.1115 | 12.5 | 30.01 | 34.58 | 0.0915 | 9.4 | 36.36 | 64.76 | 0.1233 |
| 0 | 96 | 14.8 | 42.85 | 0.1116 | 12.5 | 30.00 | 33.47 | 0.0885 | 9.5 | 35.75 | 64.90 | 0.1258 |
| 1 | 2 | 14.8 | 41.78 | 0.1101 | 12.7 | 28.79 | 34.16 | 0.0912 | 9.5 | 37.45 | 66.04 | 0.1292 |
| 1 | 3 | 14.8 | 41.25 | 0.1080 | 12.6 | 28.69 | 32.82 | 0.0869 | 9.4 | 37.12 | 65.50 | 0.1260 |
| 1 | 7 | 14.8 | 40.09 | 0.1054 | 12.7 | 28.64 | 31.51 | 0.0841 | 9.5 | 35.84 | 65.27 | 0.1274 |
| 1 | 12 | 14.8 | 41.29 | 0.1086 | 12.6 | 28.95 | 33.75 | 0.0898 | 9.4 | 36.24 | 65.54 | 0.1264 |
| 1 | 30 | 14.8 | 41.30 | 0.1079 | 12.6 | 28.39 | 33.31 | 0.0874 | 9.5 | 35.82 | 65.58 | 0.1294 |
| 1 | 35 | 14.8 | 41.22 | 0.1082 | 12.6 | 28.96 | 32.13 | 0.0849 | 9.4 | 36.77 | 66.19 | 0.1284 |
| 1 | 39 | 14.8 | 41.39 | 0.1084 | 12.7 | 29.00 | 34.21 | 0.0920 | 9.5 | 36.24 | 64.51 | 0.1248 |
| 1 | 49 | 14.8 | 41.48 | 0.1089 | 12.6 | 29.12 | 33.78 | 0.0896 | 9.5 | 37.06 | 65.84 | 0.1271 |
| 1 | 71 | 14.8 | 41.92 | 0.1103 | 12.7 | 28.67 | 33.53 | 0.0899 | 9.4 | 36.66 | 64.92 | 0.1248 |
| 1 | 90 | 14.8 | 41.45 | 0.1097 | 12.6 | 28.82 | 32.47 | 0.0850 | 9.6 | 37.79 | 65.94 | 0.1307 |
| 2 | 2 | 14.8 | 40.64 | 0.1058 | 12.8 | 28.72 | 31.95 | 0.0872 | 9.6 | 34.74 | 65.25 | 0.1272 |
| 2 | 3 | 14.9 | 40.18 | 0.1037 | 12.7 | 28.66 | 34.09 | 0.0916 | 9.5 | 35.23 | 63.73 | 0.1201 |
| 2 | 7 | 14.9 | 40.55 | 0.1052 | 12.6 | 28.86 | 33.38 | 0.0900 | 9.4 | 35.44 | 64.14 | 0.1205 |
| 2 | 12 | 14.9 | 41.36 | 0.1076 | 12.8 | 29.45 | 33.80 | 0.0920 | 9.4 | 37.25 | 63.69 | 0.1192 |
| 2 | 30 | 14.9 | 41.56 | 0.1076 | 12.7 | 29.34 | 33.01 | 0.0879 | 9.4 | 36.72 | 63.99 | 0.1205 |
| 2 | 35 | 15.0 | 42.31 | 0.1097 | 12.6 | 28.90 | 33.76 | 0.0906 | 9.6 | 35.74 | 64.73 | 0.1232 |
| 2 | 39 | 14.8 | 41.19 | 0.1083 | 12.8 | 28.63 | 33.48 | 0.0907 | 9.6 | 35.73 | 63.70 | 0.1229 |
| 2 | 49 | 14.9 | 40.28 | 0.1051 | 12.9 | 28.30 | 33.85 | 0.0915 | 9.5 | 36.46 | 64.72 | 0.1216 |
| 2 | 71 | 14.9 | 41.42 | 0.1072 | 12.7 | 28.67 | 32.03 | 0.0845 | 9.6 | 35.13 | 64.42 | 0.1250 |
| 2 | 90 | 15.0 | 41.94 | 0.1094 | 12.7 | 29.37 | 33.14 | 0.0909 | 9.5 | 37.05 | 64.08 | 0.1194 |
| 3 | 2 | 14.9 | 42.03 | 0.1094 | 12.7 | 29.30 | 34.14 | 0.0913 | 9.5 | 35.78 | 65.02 | 0.1261 |
| 3 | 3 | 14.9 | 41.54 | 0.1053 | 12.7 | 28.07 | 32.97 | 0.0883 | 9.7 | 36.86 | 66.23 | 0.1300 |
| 3 | 7 | 14.9 | 42.69 | 0.1085 | 12.8 | 28.77 | 33.35 | 0.0907 | 9.3 | 38.22 | 65.11 | 0.1238 |
| 3 | 12 | 14.9 | 42.56 | 0.1104 | 12.8 | 28.90 | 32.68 | 0.0895 | 9.5 | 37.60 | 65.64 | 0.1272 |
| 3 | 30 | 14.9 | 42.29 | 0.1085 | 12.7 | 28.88 | 32.46 | 0.0873 | 9.5 | 36.23 | 65.65 | 0.1282 |
| 3 | 35 | 14.9 | 43.25 | 0.1095 | 12.7 | 28.77 | 34.50 | 0.0940 | 9.5 | 35.32 | 66.15 | 0.1256 |
| 3 | 39 | 14.8 | 42.99 | 0.1137 | 12.8 | 28.45 | 32.76 | 0.0868 | 9.5 | 36.60 | 64.98 | 0.1268 |
| 3 | 49 | 14.9 | 41.55 | 0.1065 | 12.9 | 28.66 | 33.33 | 0.0906 | 9.5 | 36.67 | 65.83 | 0.1275 |
| 3 | 71 | 14.9 | 41.78 | 0.1070 | 12.7 | 28.47 | 32.94 | 0.0872 | 9.4 | 36.56 | 65.26 | 0.1253 |
| 3 | 90 | 15.0 | 42.75 | 0.1105 | 12.8 | 28.90 | 34.77 | 0.0959 | 9.3 | 37.39 | 64.31 | 0.1219 |
| 4 | 2 | 13.3 | 40.73 | 0.1025 | 12.2 | 34.14 | 33.44 | 0.0858 | 8.6 | 33.26 | 67.17 | 0.0994 |
| 4 | 3 | 14.7 | 42.56 | 0.1095 | 12.4 | 30.40 | 32.73 | 0.0838 | 8.8 | 33.17 | 65.70 | 0.0978 |
| 4 | 7 | 13.2 | 40.53 | 0.1060 | 12.2 | 33.23 | 34.76 | 0.0896 | 8.8 | 35.32 | 63.35 | 0.0964 |
| 4 | 12 | 14.8 | 43.12 | 0.1136 | 12.7 | 30.51 | 35.23 | 0.0922 | 9.0 | 35.16 | 64.52 | 0.0980 |
| 4 | 30 | 14.0 | 39.92 | 0.1073 | 12.4 | 31.60 | 32.71 | 0.0850 | 8.6 | 33.87 | 65.03 | 0.0901 |
| 4 | 35 | 13.6 | 41.71 | 0.1021 | 12.3 | 32.60 | 33.47 | 0.0818 | 8.7 | 35.65 | 65.19 | 0.0943 |
| 4 | 39 | 14.8 | 42.88 | 0.1150 | 12.6 | 30.02 | 32.50 | 0.0859 | 9.0 | 35.90 | 66.04 | 0.0956 |
| 4 | 49 | 13.5 | 40.13 | 0.0996 | 12.3 | 31.27 | 34.62 | 0.0897 | 8.8 | 38.14 | 63.80 | 0.0931 |
| 4 | 71 | 14.1 | 40.48 | 0.1008 | 12.3 | 31.03 | 32.63 | 0.0835 | 8.6 | 38.13 | 66.43 | 0.0979 |
| 4 | 90 | 14.3 | 40.87 | 0.1061 | 12.3 | 32.31 | 30.82 | 0.0781 | 8.7 | 35.09 | 68.39 | 0.0920 |
| 5 | 2 | 13.4 | 42.92 | 0.1056 | 12.2 | 34.11 | 33.51 | 0.0859 | 8.9 | 36.90 | 67.24 | 0.0964 |
| 5 | 3 | 14.8 | 43.79 | 0.1148 | 12.4 | 30.09 | 32.29 | 0.0839 | 8.9 | 31.91 | 65.99 | 0.1005 |
| 5 | 7 | 13.3 | 44.21 | 0.1159 | 12.2 | 33.98 | 36.21 | 0.0937 | 8.6 | 33.29 | 64.26 | 0.0980 |

| | | B-747P | | DC-8 | | | | Timeliness | | Factor Scores | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Des Pt | Rand Stream | Use Rate | G-Cycle Time | Use Rate | G-Cycle Time | Average Payload | MTM/D | Percent Ontime | Days Late | 1 | 2 | 3 | 4 |
| 0 | 3 | 9.5 | 46.23 | 9.6 | 35.27 | 17.72 | 0.0330 | 15.20 | 2.53 | 0.768 | 1.116 | -0.350 | 0.601 |
| 0 | 13 | 9.5 | 45.54 | 9.5 | 35.14 | 17.44 | 0.0315 | 14.78 | 2.52 | 0.978 | 0.136 | 0.938 | 1.114 |
| 0 | 22 | 9.7 | 45.01 | 9.5 | 35.64 | 17.25 | 0.0320 | 15.05 | 2.50 | 0.949 | 0.478 | -0.546 | 0.825 |
| 0 | 31 | 9.4 | 47.00 | 9.2 | 37.75 | 17.24 | 0.0315 | 14.86 | 2.52 | 0.657 | 0.939 | -0.933 | 0.260 |
| 0 | 41 | 9.4 | 46.92 | 9.6 | 35.62 | 17.27 | 0.0332 | 14.80 | 2.51 | 0.714 | 0.642 | -0.604 | 0.862 |
| 0 | 54 | 9.7 | 44.59 | 9.5 | 35.12 | 17.52 | 0.0324 | 14.95 | 2.51 | 1.181 | 1.297 | -0.987 | 0.981 |
| 0 | 64 | 9.9 | 42.79 | 9.6 | 35.83 | 17.32 | 0.0327 | 15.01 | 2.49 | 1.113 | 0.410 | -0.547 | 1.289 |
| 0 | 72 | 9.5 | 46.72 | 9.5 | 34.73 | 17.48 | 0.0325 | 15.01 | 2.49 | 0.788 | 0.528 | -0.340 | 0.260 |
| 0 | 83 | 9.5 | 46.05 | 9.3 | 36.17 | 17.06 | 0.0309 | 15.06 | 2.50 | 0.746 | 0.406 | 0.263 | 1.281 |
| 0 | 96 | 9.8 | 44.42 | 9.3 | 36.12 | 17.25 | 0.0299 | 15.09 | 2.49 | 0.948 | 0.695 | -0.554 | 1.337 |
| 1 | 2 | 9.5 | 46.05 | 9.3 | 37.86 | 17.53 | 0.0319 | 12.40 | 2.31 | 0.829 | -0.668 | 0.465 | 0.348 |
| 1 | 3 | 9.5 | 47.24 | 9.7 | 34.13 | 17.64 | 0.0341 | 12.22 | 2.28 | 0.896 | -0.850 | 0.035 | 0.385 |
| 1 | 7 | 9.5 | 45.57 | 9.5 | 36.16 | 17.63 | 0.0326 | 11.97 | 2.16 | 1.017 | -1.218 | -0.767 | -0.008 |
| 1 | 12 | 9.5 | 46.87 | 9.2 | 37.14 | 17.60 | 0.0310 | 12.95 | 2.18 | 0.766 | -0.769 | 0.502 | 0.190 |
| 1 | 30 | 9.5 | 46.78 | 9.2 | 36.80 | 17.08 | 0.0306 | 12.17 | 2.30 | 0.787 | -0.637 | 0.000 | 0.240 |
| 1 | 35 | 9.7 | 45.17 | 9.4 | 36.03 | 17.47 | 0.0320 | 12.41 | 2.23 | 0.826 | -0.781 | -1.018 | 0.398 |
| 1 | 39 | 9.5 | 45.77 | 9.5 | 36.38 | 17.64 | 0.0332 | 13.47 | 2.16 | 1.001 | -1.012 | 1.107 | -0.143 |
| 1 | 49 | 9.5 | 46.89 | 9.6 | 34.96 | 17.44 | 0.0331 | 12.19 | 2.23 | 0.769 | -0.822 | 0.490 | 0.302 |
| 1 | 71 | 9.5 | 46.56 | 9.6 | 34.70 | 17.66 | 0.0337 | 12.41 | 2.32 | 1.042 | -0.613 | 0.479 | 0.087 |
| 1 | 90 | 9.9 | 42.97 | 9.6 | 35.73 | 17.91 | 0.0343 | 12.65 | 2.11 | 1.172 | -0.691 | -0.834 | 0.294 |
| 2 | 2 | 9.7 | 44.10 | 9.4 | 36.39 | 17.54 | 0.0313 | 13.22 | 2.40 | 1.052 | -0.961 | -0.378 | -0.303 |
| 2 | 3 | 9.6 | 44.60 | 9.5 | 36.47 | 17.40 | 0.0317 | 12.96 | 2.38 | 0.998 | -1.500 | 1.000 | -0.309 |
| 2 | 7 | 9.6 | 44.75 | 9.2 | 37.77 | 17.42 | 0.0314 | 12.65 | 2.35 | 0.473 | -1.452 | 0.335 | -0.597 |
| 2 | 12 | 9.6 | 45.36 | 9.3 | 37.22 | 17.46 | 0.0311 | 12.67 | 2.32 | 0.612 | -1.089 | 0.762 | -0.521 |
| 2 | 30 | 9.4 | 47.16 | 9.5 | 35.17 | 17.27 | 0.0320 | 13.11 | 2.40 | 0.711 | -0.982 | 0.259 | -0.147 |
| 2 | 35 | 9.4 | 46.07 | 9.4 | 36.57 | 17.67 | 0.0333 | 12.98 | 2.37 | 0.773 | -0.901 | 0.440 | -0.743 |
| 2 | 39 | 9.6 | 44.65 | 9.3 | 36.96 | 17.55 | 0.0327 | 12.46 | 2.30 | 1.033 | -1.132 | 0.471 | -0.346 |
| 2 | 49 | 9.5 | 44.13 | 9.5 | 37.20 | 17.87 | 0.0334 | 12.65 | 2.35 | 0.985 | -1.529 | 1.186 | -1.002 |
| 2 | 71 | 9.5 | 45.67 | 9.3 | 36.26 | 17.50 | 0.0312 | 13.21 | 2.41 | 0.814 | -0.907 | -0.839 | -0.052 |
| 2 | 90 | 9.5 | 44.19 | 9.0 | 39.08 | 17.69 | 0.0305 | 12.65 | 2.33 | 0.624 | -0.640 | 0.391 | -0.397 |
| 3 | 2 | 9.4 | 46.71 | 9.3 | 38.95 | 17.64 | 0.0326 | 13.16 | 2.47 | 0.930 | 0.472 | 0.978 | 0.109 |
| 3 | 3 | 9.4 | 46.13 | 9.5 | 35.82 | 17.48 | 0.0339 | 13.10 | 2.45 | 0.791 | -0.070 | 0.369 | -0.815 |
| 3 | 7 | 9.7 | 43.75 | 9.6 | 35.36 | 17.38 | 0.0338 | 13.04 | 2.42 | 1.049 | 0.415 | 0.319 | -0.640 |
| 3 | 12 | 9.5 | 45.04 | 9.4 | 36.73 | 17.58 | 0.0323 | 13.12 | 2.40 | 1.010 | 0.494 | -0.288 | -0.135 |
| 3 | 30 | 9.6 | 45.91 | 9.7 | 35.47 | 17.58 | 0.0342 | 13.08 | 2.45 | 1.140 | 0.341 | -0.214 | 0.188 |
| 3 | 35 | 9.7 | 43.52 | 9.4 | 35.73 | 17.55 | 0.0330 | 13.10 | 2.43 | 1.107 | 0.499 | 0.756 | -0.815 |
| 3 | 39 | 9.5 | 44.85 | 9.3 | 36.90 | 17.81 | 0.0332 | 13.18 | 2.39 | 1.259 | 0.764 | -0.473 | 0.426 |
| 3 | 49 | 9.4 | 45.88 | 9.6 | 37.25 | 17.62 | 0.0339 | 13.06 | 2.44 | 1.200 | -0.028 | 0.680 | -0.398 |
| 3 | 71 | 9.4 | 46.34 | 9.4 | 35.59 | 17.69 | 0.0327 | 13.12 | 2.47 | 0.911 | 0.046 | -0.121 | 0.024 |
| 3 | 90 | 9.5 | 44.64 | 9.2 | 38.43 | 17.33 | 0.0319 | 13.04 | 2.41 | 0.867 | 0.529 | 1.588 | -0.824 |
| 4 | 2 | 9.3 | 44.02 | 9.5 | 34.39 | 17.75 | 0.0197 | 16.22 | 2.28 | -1.771 | -1.342 | -0.053 | 0.784 |
| 4 | 3 | 9.3 | 43.96 | 9.6 | 36.41 | 16.99 | 0.0218 | 15.43 | 2.33 | -0.669 | -0.365 | -1.183 | -0.528 |
| 4 | 7 | 8.7 | 41.51 | 9.9 | 33.28 | 16.85 | 0.0208 | 14.42 | 2.38 | -1.808 | -1.887 | 1.452 | 2.046 |
| 4 | 12 | 9.3 | 49.42 | 9.2 | 40.20 | 16.89 | 0.0204 | 13.79 | 2.42 | -1.492 | 0.431 | 1.846 | -1.211 |
| 4 | 30 | 9.1 | 42.01 | 9.7 | 33.75 | 16.60 | 0.0206 | 15.72 | 2.32 | -1.337 | -1.502 | -0.606 | 0.356 |
| 4 | 35 | 9.4 | 42.07 | 9.4 | 37.22 | 17.30 | 0.0235 | 14.97 | 2.35 | -1.379 | -1.148 | -0.971 | 0.407 |
| 4 | 39 | 9.0 | 39.84 | 9.8 | 33.27 | 17.60 | 0.0219 | 13.67 | 2.43 | -0.548 | -0.321 | -1.738 | -0.734 |
| 4 | 49 | 9.5 | 44.06 | 9.3 | 39.14 | 17.71 | 0.0244 | 14.58 | 2.37 | -0.862 | -1.890 | 1.209 | 0.122 |
| 4 | 71 | 9.2 | 42.18 | 9.2 | 38.03 | 17.39 | 0.0228 | 15.77 | 2.31 | -1.061 | -1.898 | -1.603 | 0.807 |
| 4 | 90 | 9.3 | 42.41 | 9.7 | 36.02 | 17.75 | 0.0209 | 14.35 | 2.39 | -1.520 | -0.718 | -2.674 | 0.459 |
| 5 | 2 | 9.0 | 41.89 | 9.6 | 34.05 | 17.70 | 0.0222 | 16.72 | 2.24 | -2.154 | 0.529 | 0.302 | 1.293 |
| 5 | 3 | 9.3 | 46.62 | 9.5 | 36.58 | 16.96 | 0.0239 | 16.50 | 2.26 | -0.336 | 1.379 | -1.376 | -0.238 |
| 5 | 7 | 9.0 | 44.17 | 9.7 | 34.59 | 17.04 | 0.0208 | 16.33 | 2.26 | -1.345 | 1.138 | 1.945 | 4.016 |

| Des Pt | Rand Stream | Factor Scores 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|
| 0 | 3 | 0.842 | 0.731 | 0.599 | 0.475 |
| 0 | 13 | 0.209 | 0.156 | 0.320 | 0.036 |
| 0 | 22 | 0.316 | -0.328 | -0.611 | -0.611 |
| 0 | 31 | 0.969 | -1.345 | -0.534 | -0.895 |
| 0 | 41 | 1.080 | 0.111 | -0.602 | -0.244 |
| 0 | 54 | 0.020 | 0.200 | -0.094 | 0.569 |
| 0 | 64 | -0.293 | 0.018 | 0.063 | 0.286 |
| 0 | 72 | 0.751 | 0.068 | -0.167 | -0.451 |
| 0 | 83 | 0.220 | -0.911 | -0.514 | 0.080 |
| 0 | 96 | -0.008 | -0.967 | -0.151 | 0.041 |
| 1 | 2 | 0.478 | -0.746 | 0.229 | -0.091 |
| 1 | 3 | 0.805 | 1.687 | 0.570 | 0.927 |
| 1 | 7 | 0.185 | 0.525 | 0.361 | 0.215 |
| 1 | 12 | 0.179 | -0.669 | 0.488 | 0.017 |
| 1 | 30 | 0.315 | -0.515 | -0.308 | 0.503 |
| 1 | 35 | 0.359 | -0.026 | 0.172 | 0.305 |
| 1 | 39 | 0.037 | 0.215 | 0.341 | -0.330 |
| 1 | 49 | 0.711 | 1.050 | 0.399 | 0.560 |
| 1 | 71 | 0.482 | 1.025 | 0.295 | 0.199 |
| 1 | 90 | -0.089 | 0.525 | 0.825 | 0.491 |
| 2 | 2 | 0.074 | 0.081 | 0.160 | -0.413 |
| 2 | 3 | -0.333 | 0.230 | -0.166 | 0.055 |
| 2 | 7 | 0.150 | -0.944 | -0.458 | -0.317 |
| 2 | 12 | 0.190 | -0.493 | -0.712 | -0.034 |
| 2 | 30 | 0.691 | 0.807 | -0.785 | 0.576 |
| 2 | 35 | 0.603 | -0.340 | 0.035 | -1.093 |
| 2 | 39 | -0.029 | -0.555 | -0.510 | -0.678 |
| 2 | 49 | 0.060 | 0.384 | 0.426 | -0.242 |
| 2 | 71 | 0.491 | -0.255 | -0.549 | -0.568 |
| 2 | 90 | 0.128 | -1.764 | -0.483 | -0.201 |
| 3 | 2 | 0.178 | -0.851 | 0.794 | -0.066 |
| 3 | 3 | 0.437 | 0.950 | 0.543 | 0.673 |
| 3 | 7 | -0.252 | 0.629 | 0.089 | 0.840 |
| 3 | 12 | 0.077 | -0.257 | 0.130 | -0.026 |
| 3 | 30 | 0.451 | 1.118 | 0.621 | 0.369 |
| 3 | 35 | -0.608 | -0.250 | 0.758 | -0.566 |
| 3 | 39 | 0.124 | -0.630 | 0.106 | -0.732 |
| 3 | 49 | 0.327 | 0.468 | 0.871 | 0.177 |
| 3 | 71 | 0.321 | 0.341 | 0.364 | 0.281 |
| 3 | 90 | -0.413 | -1.078 | -0.348 | 0.278 |
| 4 | 2 | 0.820 | -0.047 | 2.018 | -1.327 |
| 4 | 3 | 0.324 | -0.179 | -0.774 | -1.433 |
| 4 | 7 | 1.341 | 1.831 | -1.465 | -0.769 |
| 4 | 12 | 2.196 | -1.292 | -0.356 | 0.008 |
| 4 | 30 | 0.525 | 0.879 | -1.726 | -0.843 |
| 4 | 35 | 0.141 | -0.818 | -0.032 | 1.234 |
| 4 | 39 | 0.720 | 1.116 | -1.108 | -0.358 |
| 4 | 49 | 0.012 | -1.776 | 1.155 | 0.720 |
| 4 | 71 | 0.309 | -1.512 | -0.575 | 1.680 |
| 4 | 90 | 1.591 | 0.334 | 1.145 | -0.276 |
| 5 | 2 | 0.986 | 1.149 | 1.692 | 0.897 |
| 5 | 3 | 0.049 | -0.356 | -0.502 | -1.481 |
| 5 | 7 | 0.777 | 0.749 | -0.529 | -1.600 |

| | | Throughput | | | C-5A | | | | C-141B | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Des Pt | Rand Stream | Outsize Tons | Pax | Cargo Tons | Use Rate | G-Cycle Time | Average Payload | MTM/D | Use Rate | G-Cycle Time | Average Payload | MTM/D |
| 5 | 12 | 13240 | 159079 | 110765 | 10.6 | 46.87 | 63.49 | 0.1187 | 12.2 | 40.15 | 22.24 | 0.0455 |
| 5 | 30 | 12730 | 172665 | 114408 | 10.7 | 44.10 | 61.70 | 0.1226 | 12.6 | 33.27 | 22.57 | 0.0407 |
| 5 | 35 | 15481 | 167717 | 114209 | 10.8 | 44.69 | 63.53 | 0.1225 | 12.4 | 35.62 | 19.90 | 0.0419 |
| 5 | 39 | 14253 | 172435 | 113881 | 10.8 | 44.81 | 61.93 | 0.1198 | 12.3 | 35.07 | 21.17 | 0.0383 |
| 5 | 49 | 12544 | 172903 | 114380 | 11.0 | 42.63 | 61.23 | 0.1194 | 12.0 | 37.85 | 22.25 | 0.0425 |
| 5 | 71 | 14250 | 172226 | 113537 | 10.9 | 43.62 | 61.76 | 0.1200 | 12.5 | 35.29 | 18.80 | 0.0351 |
| 5 | 90 | 12562 | 180340 | 114695 | 10.9 | 44.76 | 62.25 | 0.1179 | 12.5 | 35.50 | 21.93 | 0.0398 |
| 6 | 2 | 12361 | 174695 | 111273 | 10.6 | 46.01 | 62.82 | 0.1198 | 12.4 | 35.17 | 23.79 | 0.0423 |
| 6 | 3 | 13959 | 167266 | 112416 | 10.5 | 45.51 | 61.67 | 0.1052 | 12.0 | 35.21 | 22.46 | 0.0378 |
| 6 | 7 | 14676 | 164366 | 116165 | 10.7 | 44.21 | 61.39 | 0.1232 | 12.7 | 28.06 | 25.27 | 0.0389 |
| 6 | 12 | 12488 | 160611 | 111618 | 10.7 | 46.91 | 62.84 | 0.1164 | 12.2 | 39.74 | 22.76 | 0.0461 |
| 6 | 30 | 13025 | 174101 | 117331 | 10.7 | 43.77 | 61.82 | 0.1216 | 12.7 | 32.41 | 24.13 | 0.0405 |
| 6 | 35 | 15084 | 177332 | 112733 | 10.5 | 44.67 | 62.56 | 0.1146 | 12.3 | 35.12 | 19.76 | 0.0400 |
| 6 | 39 | 14551 | 171430 | 112991 | 10.6 | 45.01 | 61.91 | 0.1158 | 12.1 | 34.99 | 20.31 | 0.0365 |
| 6 | 49 | 13094 | 167013 | 113253 | 10.7 | 44.23 | 61.77 | 0.1162 | 12.0 | 36.78 | 21.69 | 0.0395 |
| 6 | 71 | 14223 | 175457 | 112345 | 10.8 | 43.15 | 62.41 | 0.1191 | 12.2 | 37.26 | 18.88 | 0.0338 |
| 6 | 90 | 13286 | 179648 | 113479 | 10.9 | 44.25 | 61.57 | 0.1149 | 12.2 | 35.39 | 22.21 | 0.0405 |
| 7 | 2 | 20632 | 176154 | 109847 | 10.6 | 45.70 | 59.31 | 0.1124 | 12.4 | 35.87 | 23.29 | 0.0424 |
| 7 | 3 | 26813 | 170484 | 111466 | 10.5 | 44.90 | 61.96 | 0.1050 | 12.0 | 35.19 | 22.85 | 0.0381 |
| 7 | 7 | 24813 | 171714 | 111372 | 10.6 | 44.99 | 59.13 | 0.1181 | 12.7 | 28.60 | 24.26 | 0.0399 |
| 7 | 12 | 25100 | 152559 | 110339 | 10.5 | 46.73 | 61.59 | 0.1137 | 12.1 | 38.98 | 22.53 | 0.0450 |
| 7 | 30 | 25092 | 171217 | 109803 | 10.5 | 44.17 | 59.27 | 0.1133 | 12.6 | 34.39 | 23.06 | 0.0423 |
| 7 | 35 | 26216 | 170183 | 111832 | 10.5 | 44.77 | 62.01 | 0.1133 | 12.5 | 34.73 | 19.88 | 0.0415 |
| 7 | 39 | 24444 | 171824 | 109046 | 10.7 | 44.91 | 58.14 | 0.1085 | 12.0 | 36.02 | 20.02 | 0.0367 |
| 7 | 49 | 22850 | 170154 | 111355 | 10.7 | 42.95 | 60.78 | 0.1133 | 12.0 | 38.99 | 21.50 | 0.0410 |
| 7 | 71 | 28980 | 175845 | 114046 | 10.6 | 43.28 | 61.45 | 0.1162 | 12.3 | 36.50 | 18.36 | 0.0340 |
| 7 | 90 | 22333 | 177597 | 110147 | 10.8 | 43.22 | 59.23 | 0.1081 | 12.4 | 35.27 | 21.88 | 0.0412 |
| 8 | 2 | 14629 | 168378 | 120049 | 10.7 | 43.15 | 62.57 | 0.1198 | 12.3 | 32.92 | 20.97 | 0.0420 |
| 8 | 6 | 14182 | 170088 | 119642 | 10.8 | 42.35 | 60.94 | 0.1169 | 12.3 | 32.91 | 21.55 | 0.0440 |
| 8 | 20 | 13332 | 170293 | 118948 | 10.7 | 43.05 | 61.22 | 0.1177 | 12.3 | 32.67 | 20.99 | 0.0402 |
| 8 | 27 | 13008 | 171874 | 119403 | 10.8 | 42.67 | 61.20 | 0.1189 | 12.2 | 33.97 | 20.64 | 0.0409 |
| 8 | 30 | 12980 | 172574 | 118261 | 10.8 | 42.19 | 59.53 | 0.1145 | 12.3 | 33.34 | 20.86 | 0.0426 |
| 8 | 41 | 12804 | 167989 | 119064 | 10.8 | 42.57 | 61.09 | 0.1187 | 12.4 | 32.56 | 20.76 | 0.0425 |
| 8 | 44 | 13893 | 174142 | 118023 | 10.7 | 42.53 | 61.14 | 0.1166 | 12.0 | 35.09 | 21.29 | 0.0418 |
| 8 | 45 | 13087 | 172181 | 121358 | 10.9 | 42.04 | 61.97 | 0.1224 | 12.2 | 33.03 | 21.11 | 0.0421 |
| 8 | 78 | 13722 | 163771 | 118003 | 10.7 | 43.17 | 60.53 | 0.1151 | 12.2 | 33.64 | 21.25 | 0.0423 |
| 8 | 95 | 13621 | 168804 | 119330 | 10.8 | 42.39 | 61.38 | 0.1184 | 12.3 | 33.97 | 20.95 | 0.0427 |
| 9 | 3 | 14068 | 169059 | 116117 | 10.6 | 45.11 | 62.42 | 0.1145 | 12.8 | 30.50 | 22.99 | 0.0408 |
| 9 | 16 | 14012 | 188014 | 117446 | 10.6 | 45.21 | 61.85 | 0.1196 | 12.5 | 32.76 | 23.16 | 0.0461 |
| 9 | 25 | 14469 | 171495 | 118232 | 10.6 | 42.54 | 62.50 | 0.1177 | 12.4 | 33.70 | 23.33 | 0.0457 |
| 9 | 43 | 13029 | 175701 | 113854 | 10.8 | 45.41 | 61.67 | 0.1173 | 12.2 | 37.81 | 20.02 | 0.0413 |
| 9 | 50 | 15092 | 171889 | 114420 | 10.7 | 43.94 | 61.23 | 0.1186 | 12.2 | 37.15 | 22.36 | 0.0410 |
| 9 | 57 | 16016 | 171507 | 116913 | 10.7 | 44.64 | 62.65 | 0.1132 | 12.4 | 33.70 | 22.10 | 0.0458 |
| 9 | 60 | 14451 | 173420 | 119156 | 11.0 | 43.84 | 61.56 | 0.1164 | 12.4 | 33.20 | 24.36 | 0.0411 |
| 9 | 61 | 13422 | 170679 | 117738 | 10.7 | 44.98 | 61.19 | 0.1146 | 12.4 | 33.46 | 22.64 | 0.0408 |
| 9 | 78 | 13663 | 168069 | 112281 | 10.8 | 45.34 | 61.67 | 0.1150 | 11.9 | 36.21 | 20.69 | 0.0387 |
| 9 | 80 | 13834 | 170967 | 115173 | 10.6 | 43.60 | 61.73 | 0.1228 | 12.3 | 35.80 | 22.99 | 0.0490 |
| | Mean | 18242 | 171298 | 116063 | 10.76 | 43.62 | 61.05 | 0.1174 | 12.33 | 34.26 | 21.45 | 0.0416 |
| | Std Dev | 5945.3 | 4791.0 | 3475.2 | 0.13 | 1.33 | 1.10 | 0.0035 | 0.21 | 2.22 | 1.32 | 0.0025 |
| | Coef Var | 32.6% | 2.8% | 3.0% | 1.2% | 3.0% | 1.8% | 3.0% | 1.7% | 6.5% | 6.1% | 5.9% |

| | | C-17 | | | KC-10 | | | | B-747 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Des Pt | Rand Stream | Use Rate | Average Payload | MTM/D | Use Rate | G-Cycle Time | Average Payload | MTM/D | Use Rate | G-Cycle Time | Average Payload | MTM/D |
| 5 | 12 | 14.8 | 45.99 | 0.1175 | 12.7 | 30.78 | 35.19 | 0.0927 | 9.2 | 37.72 | 64.86 | 0.0983 |
| 5 | 30 | 13.9 | 42.27 | 0.1144 | 12.6 | 30.29 | 33.95 | 0.0881 | 8.7 | 35.19 | 63.98 | 0.0919 |
| 5 | 35 | 13.7 | 43.15 | 0.1061 | 12.2 | 32.41 | 33.78 | 0.0849 | 8.5 | 38.47 | 64.80 | 0.0915 |
| 5 | 39 | 14.7 | 42.88 | 0.1150 | 12.6 | 30.14 | 33.36 | 0.0856 | 8.7 | 35.44 | 65.86 | 0.0967 |
| 5 | 49 | 13.6 | 42.26 | 0.1069 | 12.3 | 31.72 | 34.93 | 0.0902 | 8.7 | 37.46 | 66.60 | 0.0969 |
| 5 | 71 | 14.3 | 41.26 | 0.1037 | 12.3 | 30.79 | 34.75 | 0.0881 | 8.3 | 36.81 | 67.05 | 0.0924 |
| 5 | 90 | 14.6 | 42.43 | 0.1120 | 12.3 | 32.47 | 30.52 | 0.0775 | 8.8 | 34.02 | 69.70 | 0.0982 |
| 6 | 2 | 13.9 | 42.13 | 0.1091 | 12.4 | 33.77 | 32.44 | 0.0841 | 9.0 | 36.37 | 67.69 | 0.1000 |
| 6 | 3 | 14.7 | 43.54 | 0.1123 | 12.5 | 29.77 | 32.21 | 0.0839 | 8.4 | 34.62 | 64.18 | 0.0928 |
| 6 | 7 | 13.6 | 44.04 | 0.1166 | 12.3 | 31.48 | 34.80 | 0.0911 | 8.6 | 35.28 | 64.56 | 0.0938 |
| 6 | 12 | 14.8 | 46.82 | 0.1220 | 12.7 | 30.63 | 34.54 | 0.0913 | 9.2 | 35.50 | 63.29 | 0.0951 |
| 6 | 30 | 14.3 | 43.85 | 0.1193 | 12.6 | 30.36 | 33.21 | 0.0873 | 9.0 | 35.63 | 63.89 | 0.0950 |
| 6 | 35 | 14.2 | 43.60 | 0.1114 | 12.3 | 31.98 | 33.60 | 0.0861 | 8.9 | 39.03 | 66.11 | 0.0968 |
| 6 | 39 | 14.6 | 44.65 | 0.1196 | 12.7 | 29.89 | 32.35 | 0.0847 | 8.9 | 35.98 | 65.09 | 0.0945 |
| 6 | 49 | 14.2 | 43.04 | 0.1122 | 12.5 | 31.89 | 35.22 | 0.0908 | 8.9 | 40.18 | 64.76 | 0.0981 |
| 6 | 71 | 14.5 | 41.63 | 0.1045 | 12.5 | 29.45 | 32.91 | 0.0856 | 8.8 | 38.57 | 65.30 | 0.0954 |
| 6 | 90 | 14.7 | 42.08 | 0.1125 | 12.6 | 31.22 | 31.27 | 0.0820 | 8.9 | 33.04 | 68.92 | 0.0953 |
| 7 | 2 | 14.0 | 40.32 | 0.1048 | 12.4 | 33.46 | 33.63 | 0.0899 | 8.7 | 34.18 | 66.69 | 0.0966 |
| 7 | 3 | 14.7 | 41.56 | 0.1063 | 12.5 | 30.19 | 31.81 | 0.0825 | 8.7 | 32.11 | 64.40 | 0.0976 |
| 7 | 7 | 13.6 | 40.69 | 0.1069 | 12.3 | 33.04 | 34.59 | 0.0918 | 8.4 | 34.49 | 63.40 | 0.0928 |
| 7 | 12 | 14.8 | 45.68 | 0.1185 | 12.6 | 32.34 | 34.93 | 0.0912 | 9.4 | 36.51 | 65.18 | 0.1013 |
| 7 | 30 | 14.4 | 40.04 | 0.1137 | 12.6 | 30.34 | 32.46 | 0.0851 | 8.4 | 34.38 | 63.44 | 0.0887 |
| 7 | 35 | 14.2 | 40.15 | 0.1039 | 12.5 | 30.76 | 33.86 | 0.0876 | 8.7 | 40.99 | 65.83 | 0.0940 |
| 7 | 39 | 14.7 | 42.38 | 0.1161 | 12.8 | 29.38 | 32.59 | 0.0875 | 8.6 | 34.02 | 65.60 | 0.0936 |
| 7 | 49 | 14.1 | 42.03 | 0.1099 | 12.4 | 30.62 | 33.25 | 0.0867 | 8.7 | 39.71 | 65.61 | 0.0977 |
| 7 | 71 | 14.4 | 40.51 | 0.1036 | 12.3 | 29.54 | 34.26 | 0.0863 | 8.6 | 38.40 | 66.95 | 0.0987 |
| 7 | 90 | 14.7 | 41.25 | 0.1081 | 12.7 | 30.36 | 32.63 | 0.0864 | 8.4 | 32.81 | 68.73 | 0.0878 |
| 8 | 2 | 14.8 | 43.39 | 0.1126 | 12.8 | 28.34 | 32.45 | 0.0878 | 9.5 | 36.77 | 65.50 | 0.1274 |
| 8 | 6 | 14.9 | 42.12 | 0.1094 | 12.7 | 29.73 | 35.48 | 0.0959 | 9.5 | 37.17 | 64.80 | 0.1237 |
| 8 | 20 | 14.9 | 43.54 | 0.1121 | 12.9 | 28.14 | 32.96 | 0.0883 | 9.4 | 37.68 | 65.66 | 0.1275 |
| 8 | 27 | 14.8 | 43.36 | 0.1129 | 12.7 | 28.41 | 34.04 | 0.0923 | 9.6 | 36.48 | 64.16 | 0.1231 |
| 8 | 30 | 14.7 | 42.77 | 0.1122 | 12.5 | 30.06 | 32.22 | 0.0841 | 9.4 | 36.63 | 66.32 | 0.1277 |
| 8 | 41 | 14.7 | 42.22 | 0.1112 | 12.7 | 28.40 | 33.88 | 0.0910 | 9.6 | 36.06 | 65.04 | 0.1255 |
| 8 | 44 | 14.9 | 42.72 | 0.1101 | 12.9 | 28.10 | 33.16 | 0.0904 | 9.4 | 35.78 | 63.31 | 0.1170 |
| 8 | 45 | 14.9 | 41.79 | 0.1093 | 12.7 | 28.34 | 34.39 | 0.0922 | 9.3 | 37.33 | 65.36 | 0.1225 |
| 8 | 78 | 14.9 | 43.15 | 0.1108 | 12.7 | 28.89 | 33.54 | 0.0898 | 9.4 | 36.97 | 65.30 | 0.1236 |
| 8 | 95 | 14.9 | 41.84 | 0.1094 | 12.6 | 29.16 | 33.00 | 0.0889 | 9.6 | 35.90 | 65.35 | 0.1279 |
| 9 | 3 | 14.4 | 43.24 | 0.1115 | 12.5 | 30.83 | 33.53 | 0.0863 | 8.9 | 37.26 | 65.11 | 0.0902 |
| 9 | 16 | 13.3 | 42.07 | 0.1003 | 12.2 | 31.53 | 35.19 | 0.0903 | 8.5 | 33.50 | 66.01 | 0.0927 |
| 9 | 25 | 13.7 | 43.75 | 0.1084 | 12.3 | 31.62 | 35.18 | 0.0911 | 8.8 | 34.70 | 65.82 | 0.0974 |
| 9 | 43 | 14.8 | 41.12 | 0.1080 | 12.7 | 31.12 | 32.71 | 0.0861 | 9.5 | 35.59 | 65.24 | 0.1071 |
| 9 | 50 | 13.9 | 42.94 | 0.1078 | 12.4 | 31.16 | 33.85 | 0.0864 | 7.7 | 32.78 | 65.69 | 0.0815 |
| 9 | 57 | 13.2 | 42.64 | 0.1012 | 12.2 | 31.21 | 34.29 | 0.0886 | 8.5 | 34.17 | 66.72 | 0.0893 |
| 9 | 60 | 14.2 | 41.46 | 0.1069 | 12.5 | 29.92 | 32.57 | 0.0847 | 8.8 | 34.60 | 66.49 | 0.0986 |
| 9 | 61 | 14.7 | 42.70 | 0.1109 | 12.5 | 30.69 | 32.52 | 0.0836 | 9.4 | 37.78 | 65.30 | 0.1005 |
| 9 | 78 | 12.8 | 43.13 | 0.1010 | 12.2 | 32.65 | 31.02 | 0.0786 | 8.7 | 34.65 | 67.07 | 0.0906 |
| 9 | 80 | 13.4 | 42.35 | 0.1086 | 12.2 | 31.51 | 34.77 | 0.0879 | 9.2 | 34.30 | 65.66 | 0.1058 |
| | Mean | 14.48 | 42.25 | 0.1095 | 12.56 | 30.13 | 33.40 | 0.0880 | 9.11 | 36.06 | 65.38 | 0.1102 |
| | Std Dev | 0.53 | 1.30 | 0.0044 | 0.19 | 1.55 | 1.09 | 0.0035 | 0.42 | 1.66 | 1.20 | 0.0152 |
| | Coef Var | 3.7% | 3.1% | 4.0% | 1.5% | 5.1% | 3.3% | 4.0% | 4.6% | 4.6% | 1.8% | 13.8% |

| | | B-747P | | DC-8 | | | | Timeliness | | Factor Scores | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Des Pt | Rand Stream | Use Rate | G-Cycle Time | Use Rate | G-Cycle Time | Average Payload | MTM/D | Percent Ontime | Days Late | **1** | **2** | **3** | **4** |
| 5 | 12 | 9.4 | 46.98 | 9.6 | 38.44 | 17.37 | 0.0254 | 16.18 | 2.27 | -1.254 | 2.384 | 2.097 | -1.779 |
| 5 | 30 | 8.8 | 42.24 | 9.8 | 33.83 | 16.77 | 0.0199 | 16.55 | 2.26 | -0.787 | 0.692 | 0.013 | 1.043 |
| 5 | 35 | 9.0 | 43.12 | 9.5 | 37.25 | 17.54 | 0.0242 | 16.27 | 2.27 | -1.449 | 0.521 | 0.040 | 0.918 |
| 5 | 39 | 8.9 | 41.02 | 9.7 | 34.15 | 17.22 | 0.0229 | 16.28 | 2.27 | -0.528 | 1.045 | -0.887 | -0.085 |
| 5 | 49 | 9.4 | 43.23 | 9.2 | 38.63 | 17.44 | 0.0255 | 16.27 | 2.27 | -0.608 | 0.170 | 0.540 | 0.563 |
| 5 | 71 | 9.4 | 43.11 | 9.6 | 34.00 | 17.32 | 0.0223 | 16.52 | 2.25 | -0.755 | -0.583 | -0.387 | 1.001 |
| 5 | 90 | 9.4 | 42.00 | 9.3 | 38.83 | 18.38 | 0.0226 | 16.35 | 2.26 | -0.822 | 1.412 | -3.093 | 0.872 |
| 6 | 2 | 9.3 | 42.73 | 9.7 | 35.76 | 17.81 | 0.0228 | 18.12 | 2.16 | -1.425 | 0.866 | -0.323 | 0.370 |
| 6 | 3 | 8.9 | 41.42 | 9.8 | 34.07 | 17.63 | 0.0229 | 17.66 | 2.19 | -0.823 | 0.714 | -0.519 | -2.528 |
| 6 | 7 | 8.9 | 43.09 | 9.6 | 34.64 | 16.89 | 0.0200 | 17.29 | 2.21 | -1.142 | 1.288 | 1.179 | 2.277 |
| 6 | 12 | 9.2 | 43.58 | 9.4 | 39.51 | 17.61 | 0.0241 | 16.86 | 2.22 | -1.058 | 2.940 | 1.438 | -1.921 |
| 6 | 30 | 9.0 | 41.55 | 9.5 | 34.97 | 16.78 | 0.0197 | 17.95 | 2.18 | -0.424 | 1.725 | -0.511 | 1.265 |
| 6 | 35 | 9.5 | 45.36 | 9.2 | 38.43 | 16.80 | 0.0218 | 17.44 | 2.20 | -1.282 | 0.710 | -0.817 | -0.012 |
| 6 | 39 | 9.0 | 41.50 | 9.3 | 37.36 | 17.55 | 0.0222 | 16.86 | 2.23 | -0.615 | 1.785 | -1.201 | -1.241 |
| 6 | 49 | 9.4 | 44.95 | 9.1 | 40.14 | 17.14 | 0.0228 | 17.30 | 2.21 | -1.016 | 0.727 | 1.140 | -0.609 |
| 6 | 71 | 9.5 | 40.67 | 9.3 | 35.68 | 17.35 | 0.0222 | 17.94 | 2.17 | -0.236 | -0.226 | -1.127 | -0.334 |
| 6 | 90 | 9.4 | 43.62 | 10.1 | 33.00 | 18.19 | 0.0243 | 17.19 | 2.21 | -0.106 | 0.809 | -1.945 | -0.510 |
| 7 | 2 | 9.4 | 42.04 | 9.2 | 40.71 | 18.17 | 0.0216 | 18.38 | 2.13 | -1.494 | -1.240 | 0.548 | -0.476 |
| 7 | 3 | 9.2 | 39.89 | 9.9 | 33.30 | 17.39 | 0.0216 | 18.21 | 2.15 | -0.654 | -0.887 | -0.575 | -2.633 |
| 7 | 7 | 9.3 | 40.20 | 9.6 | 36.61 | 17.30 | 0.0211 | 18.15 | 2.15 | -1.431 | -1.586 | 1.301 | 1.402 |
| 7 | 12 | 9.2 | 44.36 | 9.6 | 36.86 | 16.89 | 0.0245 | 18.03 | 2.15 | -1.625 | 1.424 | 2.035 | -2.333 |
| 7 | 30 | 9.1 | 42.33 | 9.8 | 35.40 | 16.91 | 0.0222 | 18.28 | 2.15 | -1.159 | -1.178 | -0.436 | -0.671 |
| 7 | 35 | 9.0 | 45.73 | 9.3 | 36.11 | 17.56 | 0.0235 | 18.10 | 2.15 | -1.310 | -1.587 | 0.391 | -0.614 |
| 7 | 39 | 9.0 | 41.32 | 9.2 | 38.59 | 17.68 | 0.0237 | 18.13 | 2.15 | -0.620 | -0.418 | -1.012 | -2.364 |
| 7 | 49 | 9.4 | 42.97 | 9.2 | 39.50 | 17.67 | 0.0239 | 18.09 | 2.16 | -0.931 | -0.452 | -0.036 | -1.298 |
| 7 | 71 | 9.3 | 43.03 | 9.4 | 35.20 | 17.26 | 0.0207 | 18.25 | 2.14 | -0.764 | -1.756 | -0.499 | -0.401 |
| 7 | 90 | 9.3 | 44.18 | 10.1 | 33.42 | 17.86 | 0.0234 | 18.17 | 2.16 | -0.454 | -1.059 | -1.100 | -1.140 |
| 8 | 2 | 9.4 | 46.03 | 9.4 | 36.21 | 17.21 | 0.0313 | 13.82 | 2.65 | 0.803 | 1.194 | -0.355 | 0.120 |
| 8 | 6 | 9.5 | 45.12 | 9.5 | 35.81 | 17.15 | 0.0315 | 13.23 | 2.50 | 0.899 | -0.072 | 1.488 | 0.267 |
| 8 | 20 | 9.5 | 45.41 | 9.5 | 37.36 | 17.58 | 0.0333 | 13.83 | 2.66 | 0.930 | 0.930 | -0.229 | -0.194 |
| 8 | 27 | 9.7 | 42.74 | 9.4 | 36.10 | 17.51 | 0.0315 | 13.78 | 2.65 | 1.146 | 0.749 | 0.341 | -0.025 |
| 8 | 30 | 9.7 | 44.23 | 9.3 | 35.63 | 17.13 | 0.0308 | 13.78 | 2.66 | 0.582 | 0.463 | -1.681 | 0.596 |
| 8 | 41 | 9.7 | 42.44 | 9.5 | 36.69 | 17.61 | 0.0339 | 13.88 | 2.64 | 1.086 | 0.380 | 0.362 | 0.370 |
| 8 | 44 | 9.5 | 45.05 | 9.3 | 36.22 | 17.67 | 0.0326 | 14.14 | 2.64 | 1.184 | 0.327 | 0.280 | -1.097 |
| 8 | 45 | 9.6 | 43.84 | 9.5 | 36.00 | 17.55 | 0.0334 | 13.16 | 2.34 | 1.372 | 0.269 | 0.689 | 0.515 |
| 8 | 78 | 9.4 | 46.79 | 9.4 | 36.65 | 17.28 | 0.0316 | 13.60 | 2.61 | 0.495 | 0.537 | 0.440 | -0.471 |
| 8 | 95 | 9.6 | 43.64 | 9.3 | 37.16 | 17.46 | 0.0321 | 13.80 | 2.66 | 0.899 | 0.330 | -0.168 | 0.288 |
| 9 | 3 | 8.9 | 40.72 | 9.4 | 36.47 | 16.85 | 0.0206 | 26.64 | 1.62 | -0.811 | 1.033 | -0.115 | 0.461 |
| 9 | 16 | 9.1 | 38.54 | 9.5 | 34.69 | 16.91 | 0.0216 | 28.61 | 1.67 | -0.600 | -0.396 | 0.497 | 1.215 |
| 9 | 25 | 8.7 | 40.63 | 9.7 | 32.63 | 17.77 | 0.0222 | 26.64 | 1.60 | -0.320 | 0.613 | 1.592 | 0.174 |
| 9 | 43 | 9.5 | 42.22 | 9.8 | 34.93 | 17.36 | 0.0278 | 24.82 | 1.73 | 0.208 | 0.128 | -0.338 | -1.261 |
| 9 | 50 | 9.2 | 40.44 | 9.3 | 35.04 | 17.40 | 0.0236 | 25.53 | 1.64 | -0.800 | 0.352 | 0.067 | -0.436 |
| 9 | 57 | 8.8 | 41.10 | 9.6 | 35.07 | 17.76 | 0.0229 | 27.76 | 1.59 | -0.827 | -0.159 | 0.918 | -0.043 |
| 9 | 60 | 8.8 | 39.17 | 9.3 | 34.70 | 17.62 | 0.0206 | 25.17 | 1.68 | 0.135 | 0.412 | -0.735 | 0.464 |
| 9 | 61 | 9.9 | 41.53 | 9.7 | 33.72 | 17.54 | 0.0257 | 25.06 | 1.70 | 0.190 | 0.729 | -0.479 | -0.444 |
| 9 | 78 | 8.8 | 41.29 | 9.5 | 34.62 | 17.84 | 0.0238 | 26.43 | 1.71 | -1.269 | 0.288 | -1.169 | -0.697 |
| 9 | 80 | 9.4 | 45.10 | 9.9 | 35.96 | 17.88 | 0.0253 | 24.98 | 1.70 | -0.531 | 0.292 | 1.773 | 0.253 |
| | Mean | 9.37 | 43.95 | 9.48 | 36.16 | 17.44 | 0.0275 | 16.02 | 2.28 | 0.000 | 0.000 | 0.000 | 0.000 |
| | Std Dev | 0.27 | 2.17 | 0.21 | 1.71 | 0.33 | 0.0051 | 3.91 | 0.25 | 1.000 | 1.000 | 1.000 | 1.000 |
| | Coef Var | 2.9% | 4.9% | 2.2% | 0.05 | 0.02 | 0.1865 | 24.4% | 11.0% | | | | |

| Des Pt | Rand Stream | Factor Scores 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|
| 5 | 12 | 1.686 | 0.441 | 0.767 | 1.223 |
| 5 | 30 | -0.266 | 1.294 | -1.962 | 0.288 |
| 5 | 35 | 0.208 | -0.039 | 0.397 | 2.761 |
| 5 | 39 | -0.194 | 1.047 | -0.924 | 0.593 |
| 5 | 49 | -0.632 | -2.255 | 1.477 | 0.499 |
| 5 | 71 | -0.286 | 0.585 | 0.265 | 2.215 |
| 5 | 90 | 0.491 | -1.654 | 2.901 | -0.866 |
| 6 | 2 | 0.548 | 0.797 | 2.250 | 0.214 |
| 6 | 3 | -0.407 | 1.629 | -0.945 | -0.780 |
| 6 | 7 | 0.219 | 0.521 | -1.236 | -1.132 |
| 6 | 12 | 0.901 | -0.839 | 0.105 | -0.537 |
| 6 | 30 | -0.617 | 0.042 | -2.338 | -0.651 |
| 6 | 35 | 0.054 | -1.498 | -1.105 | 2.070 |
| 6 | 39 | -0.183 | -0.761 | -1.224 | 0.107 |
| 6 | 49 | -0.011 | -2.238 | -0.292 | 1.285 |
| 6 | 71 | -1.364 | -0.506 | -0.793 | 2.640 |
| 6 | 90 | 0.316 | 2.130 | 2.561 | -1.052 |
| 7 | 2 | 0.150 | -2.562 | 2.279 | -2.546 |
| 7 | 3 | -0.724 | 2.224 | -0.867 | -1.194 |
| 7 | 7 | -0.098 | -0.420 | -0.743 | -2.209 |
| 7 | 12 | 1.787 | 0.967 | -0.480 | 0.311 |
| 7 | 30 | 0.375 | 0.943 | -2.347 | -1.299 |
| 7 | 35 | 0.251 | 0.334 | -0.518 | 2.542 |
| 7 | 39 | -0.141 | -1.853 | -1.097 | -2.069 |
| 7 | 49 | -0.174 | -1.862 | 0.295 | 0.920 |
| 7 | 71 | -0.732 | 0.168 | -0.756 | 2.594 |
| 7 | 90 | 0.358 | 1.880 | 1.318 | -1.867 |
| 8 | 2 | 0.617 | 0.386 | -0.640 | 0.795 |
| 8 | 6 | -0.018 | 0.109 | -0.363 | -0.017 |
| 8 | 20 | 0.691 | 0.057 | -0.114 | 0.160 |
| 8 | 27 | -0.210 | -0.391 | -0.414 | -0.021 |
| 8 | 30 | 0.710 | -0.771 | -0.624 | -0.220 |
| 8 | 41 | 0.159 | -0.021 | 0.109 | -0.232 |
| 8 | 44 | -0.360 | -0.450 | -0.428 | -0.482 |
| 8 | 45 | -0.742 | 0.153 | 0.364 | 0.642 |
| 8 | 78 | 1.010 | 0.027 | -0.353 | 0.017 |
| 8 | 95 | 0.257 | -0.611 | 0.117 | 0.005 |
| 9 | 3 | -2.035 | -0.033 | -2.183 | 0.121 |
| 9 | 16 | -4.070 | -0.465 | -0.368 | -0.609 |
| 9 | 25 | -2.943 | 1.493 | 0.678 | -0.418 |
| 9 | 43 | -1.620 | 1.237 | 0.300 | 0.858 |
| 9 | 50 | -2.673 | -0.740 | 0.012 | -0.702 |
| 9 | 57 | -2.911 | 0.595 | 1.208 | -0.167 |
| 9 | 60 | -2.974 | -0.392 | 0.098 | -1.314 |
| 9 | 61 | -1.508 | 1.215 | -0.015 | 0.154 |
| 9 | 78 | -1.771 | 0.476 | 1.677 | 0.799 |
| 9 | 80 | -1.146 | 1.134 | 2.444 | -0.280 |
| | Mean | 0.000 | 0.000 | 0.000 | 0.000 |
| | Std Dev | 1.000 | 1.000 | 1.000 | 1.000 |
| | Coef Var | | | | |

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This research evaluated the effects of perturbations in time-phased force deployment data (TPFDD) on airlift system performance. Four characteristics of two TPFDD files were perturbed according to a $2^{4-1}$ fractional factorial experimental design and then fed into the Airlift Flow Module (AFM) simulation. Specifically, small, constrained perturbations were made to the specified locations, the timeline, the amounts of cargo and passengers, and the proportion of outsize and oversize cargo categories. The effects these perturbations had on AFM output were interpreted using factor analysis. The computed factor scores, when plotted against one another, provided sensitivity plots, graphically depicting the sensitivity of the airlift performance response to the perturbations. Counter to recent airlift analysis discussions which promote completely unconstrained random TPFDD generation, this research indicated that small, constrained variations could cause potentially significant and unpredictable changes in airlift performance. Of potential interest to the simulation community, another by-product of this research was the potential to use factor analysis as a verification and validation tool for large, complex simulation models.

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